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Language and color perception : the case of the Italian and French blue semantics : a contrastive analysis of linguistic categorizations and cognitive functions in monolingual and bilingual speakers

Camilla Simoncelli

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Membre de l'université Paris Lumières

Camilla Simoncelli

Language and color perception: the case of the Italian and French blue semantics. A contrastive analysis of linguistic categorizations and cognitive functions in monolingual and bilingual speakers.

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en vue de l'obtention du doctorat de Sciences du langage de l'Université Paris
Nanterre sous la direction de M. Philippe Gréa (Université Paris Nanterre)
et de Mme Maria Kihlstedt (Université Paris Nanterre)

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“Color has got me. I no longer need
To chase after it. It has got me for ever.
I know it. That is the meaning of this happy hour.”

(Paul Klee, 1879 - 1940)

*A mia nonna Angela,
Che mi ha sempre creduto capace di qualsiasi cosa.*

*A ma grand-mère Angèle,
Qui a toujours cru que j'étais capable de tout.*

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English Abstract

Language and color perception: the case of the Italian and French blue semantics. A contrastive analysis of linguistic categorizations and cognitive functions in monolingual and bilingual speakers.

This PhD thesis intervenes in the line of studies about the relationship between language and cognition in correlation with bilingualism, which has often shown a positive effect on general cognitive functions. A domain for studying cross-linguistic effects arising from conceptual differences across speakers of different languages is colour naming and categorisation (Harnad 1987; Roberson et al. 2004; van Kruysbergen, Bosman, and de Weert 1997; Taylor 2003; Davidoff, Davies, and Roberson 1999). Since boundaries of the color spectrum are supposed to vary cross-linguistically affecting colour perception, the bilingual's cognitive representation of colour varies depending on the language. To understand the impact of lexical categories on color perception, we compared highly proficient French-Italian bilinguals' colour naming and categorisation to monolingual speakers of the corresponding languages. In fact, Italian is supposed to have two separate basic colour terms for the blue spectrum (Paggetti, Menegaz, and Paramei 2016; Uusküla 2009): one categorizes light blue hues (*azzurro*) and one dark blue hues (*blu*); whereas French lacks this distinction. We used two behavioural experiments, a Color Word Stroop Test and a Speeded Colour Discrimination Task, to empirically verify the hypothesis, which has been confirmed: Italian monolinguals discriminate more accurately and more rapidly colours belonging to the two different blue linguistic categories (*blu* or *azzurro*) compared to colours labelled with the same colour word. Latencies for BLU color word stimuli are different based on the lightness of blue hues, too. This category effect is absent in French monolinguals, even though they have a stronger prototypicality for dark and light blue hues. Finally, despite the emergence of a specific perceptual behaviour, bilinguals globally performed like Italian monolinguals, demonstrating that their second language categories dominate their mother tongue, as well as attesting that lexical distinctions influence perceptual faculties in general. However, color perception is not directly impacted only

by language, rather by a combination of cognitive functions acting through a top-down modulation.

Keywords: visual perception, color naming, cross-linguistic variation, blue spectrum, cognitive semantics, Italian, French, bilingualism.

French Abstract

Langage et perception chromatique : la sémantique du bleu en italien et en français. Une analyse contrastive de la catégorisation linguistique et des fonctions cognitives chez les locuteurs monolingues et bilingues.

Cette thèse de doctorat s'inscrit dans la ligne d'études concernant la relation entre le langage et la cognition humaine en corrélation avec le bilinguisme, qui a souvent montré un effet positif sur les fonctions cognitives générales. Un domaine de recherche qui vise l'exploration des effets interlangues provenant des différences conceptuelles parmi les locuteurs de langues variées est le lexique chromatique et sa correspondante catégorisation (Harnad 1987; Roberson et al. 2004; van Kruysbergen, Bosman, and de Weert 1997; Taylor 2003; Davidoff, Davies, and Roberson 1999). Du fait que les frontières du spectre chromatique soient censées varier d'une langue à l'autre en exerçant une influence sur la perception des couleurs, la représentation cognitive des couleurs des bilingues varie en fonction de la langue. Pour comprendre l'impact des catégories lexicales sur la perception des couleurs, nous avons comparé la catégorisation et la dénomination chromatique de bilingues franco-italiens de niveau avancé avec celle des deux groupes de monolingues. En effet, il a été attesté que l'italien possède deux termes basiques de couleurs séparés pour la région du bleu du spectre chromatique (Paggetti, Menegaz, et Paramei 2016; Uusküla 2009) : un pour catégoriser les nuances de bleu clair (*azzurro*) et un autre pour les nuances de bleu foncé (*blu*) ; en revanche, en français cette distinction est absente. Nous avons utilisé deux expériences comportementales, le Color Word Stroop Test et le Speeded Colour Discrimination Task, pour vérifier empiriquement l'hypothèse, qui ensuite a été confirmée : les monolingues italiens distinguent plus rapidement et de façon plus précise les couleurs appartenant aux deux différentes catégories linguistiques du bleu (*blu* ou *azzurro*) par rapport aux couleurs linguistiquement identifiées par le même mot de couleur. De plus, les latences pour les stimuli du mot BLU diffèrent en fonction de la luminance des nuances de bleu. Cet effet de catégorie manque en français, malgré une prototypicalité particulièrement forte pour

les teintes de bleu clair. Pour finir, malgré l'émergence de comportements perceptifs spécifiques, les performances des bilingues sont similaires à celles des italiens monolingues. Cela démontre que les catégories de leur langue seconde (dans notre cas l'italien) dominent leur langue maternelle (ici le français) et atteste que les distinctions lexicales influencent les facultés perceptuelles en général. Pourtant, la perception des couleurs n'est pas directement impactée seulement par le langage, mais plutôt par une combinaison de fonctions cognitives qui agissent avec une modulation top-down.

Mots-clé : perception visuelle, lexique chromatique, variation cross-linguistique, spectre chromatique, bleu, sémantique cognitive, italien, français, bilinguisme.

Italian Abstract

Linguaggio e percezione cromatica: la semantica del blu in italiano e in francese. Un'analisi contrastiva della categorizzazione linguistica e delle funzioni cognitive in locutori monolingui e bilingui.

Questa tesi di dottorato si iscrive nella linea di studi che riguardano la relazione tra il linguaggio e la cognizione umana in correlazione con il bilinguismo, che ha spesso dimostrato di avere degli effetti positivi sulle funzioni cognitive generali. Un ambito di ricerca per l'analisi degli effetti inter-linguistici provenienti da differenze concettuali è il color naming, o denominazione cromatica, e la categorizzazione ad esso correlata (Harnad 1987; Roberson et al. 2004; van Kruysbergen, Bosman, and de Weert 1997; Taylor 2003; Davidoff, Davies, and Roberson 1999). Siccome le frontiere dello spettro cromatico sembrano variare da una lingua all'altra esercitando un'influenza sulla percezione dei colori, la rappresentazione cognitiva dei colori dei locutori bilingui cambia in funzione della lingua. Per comprendere l'impatto delle categorie lessicali sulla percezione dei colori, abbiamo paragonato le categorie e il color naming di bilingui franco-italiani di alta competenza linguistica con quelli dei locutori monolingui delle due lingue corrispondenti. Infatti, studi precedenti hanno mostrato che l'italiano possiede due termini cromatici di base per lo spettro del blu (Paggetti, Menegaz, and Paramei 2016; Uusküla 2009): uno per categorizzare le tinte blu chiaro (*azzurro*) e uno per le tinte blu scuro (*blu*); questa distinzione, per contro, è assente in francese. Nella nostra ricerca abbiamo utilizzato due esperimenti comportamentali, il Color Word Stroop Test e lo Speeded Colour Discrimination Task, per verificare empiricamente l'ipotesi, in seguito confermata: gli italiani monolingui distinguono più rapidamente e accuratamente i colori appartenenti alle due categorie linguistiche distinte del blu (*blu* o *azzurro*) rispetto ai colori identificati con la stessa parola. Inoltre, le latenze per gli stimoli della parola BLU sono diverse variando in funzione della luminosità del colore blu. Questo effetto di categoria non è presente nei monolingui francesi, nonostante possiedano, in compenso, una forte prototipicità per le tinte blu chiaro e blu scuro. Per finire, malgrado l'insorgenza di

comportamenti percettivi specifici, le performance dei bilingui sono globalmente simili a quelle degli italiani monolingui: questo aspetto dimostra che le categorie della loro seconda lingua dominano la loro lingua madre e attesta che le distinzioni lessicali influenzano le facoltà percettive in generale. Tuttavia, la percezione cromatica non è influenzata direttamente solo dal linguaggio; si tratta piuttosto di una combinazione di varie funzioni cognitive che agiscono attraverso una modulazione di tipo top-down.

Parole-chiave: percezione visiva, lessico cromatico, variazione interlinguistica, spettro di colori, blu, semantica cognitiva, italiano, francese, bilinguismo.

List of Abbreviations

Abbreviations	Definition
L1	First Language
L2	Second Language
CP	Categorical Perception
CA	Category Advantage
RT	Reaction Time
ACC	Accuracy
SE	Standard Error
Bil.French	Bilingual speakers tested in the French experimental block
Bil.Italian	Bilingual speakers tested in the Italian experimental block
RT	Reaction Time
ACC	Accuracy
No Int Block	No Interference Block
Verb Int Block	Verbal Interference Block
Spat Int Block	Spatial Interference Block

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Introduction

One of the most debated arguments in cognitive science is the influence of language on thought. Several studies of various domains have, in fact, tried to analyse the link between linguistic processes and conceptual and cognitive functions in order to understand whether language can really have an impact on cognition or whether thought processes, like memory, attention, problem solving, perception and executive functions, are completely independent (Thierry 2016; Gordon 2004; Pica et al. 2004).

The assumption that speaking different languages can determine a different conceptualisation and categorisation of the world, leading to distinct perceptions, is part of the linguistic relativism introduced by Sapir and Whorf (Whorf 1956). On the opposite side, we find the universalist theory, mainly supported by Berlin and Kay (Berlin and Kay 1969), which states that there exist universal concepts transcending language diversity.

The unsolved controversy between these two theoretical positions has been the heart of several empirical studies (Boroditsky, Schmidt, and Phillips 2002; Boroditsky 2001; Lupyan 2012; Pinker 1995) which have obtained divergent results, especially in the territory of perception, through behavioural and neurophysiological measures (Thierry et al. 2015; Thierry et al. 2009b; Pulvermüller and Shtyrov 2006; Garbin et al. 2010). At the same time, reality is partitioned into categories which do not objectively exist since categorization is an intrinsic human ability based on conventions, as assumed by Edmund Leach (Leach 1973):

“I postulate that the physical and social environment of a young child is perceived as a continuum. It does not contain any intrinsically separate 'things'. The child, in due course, is taught to impose upon this environment a kind of discriminating grid which serves to distinguish the world as being composed of a large number of separate things, each labelled with a name. This world is a representation of our language categories, not vice versa. Because my mother tongue is English, it seems self-evident that bushes and trees are different kinds of things. I would not think this unless I had been taught that it was the case.” (Leach 1973: 34).

Following Leach's statements, categorization depends on language in such a way that the continuum of the reality is shared in discrete entities named with language-specific words, varying cross-linguistically (Taylor 2003). One area of the experience subjugated to a three-dimensional continuum is color. In fact, since the human eye can distinguish more than 7 million colours (Brown and Lenneberg 1954), the chromatic spectrum is segmented in arbitrary sections, defined by the three criteria of hue, saturation and brightness, by each language system which assigns them linguistic labels. Languages, thus, differ in the number of color terms, as well as in the set of color hues denoted by these terms (Grossmann 2016). Therefore, if two colours are named with the same word in one language, speakers of that language will judge them more similar than speakers of another language, assigning them two distinct color words. The most studied example of color terms' cross-linguistic variations is the blue color, which has a special place in the group of the Basic Color Terms, following the definition of Berlin and Kay (Berlin and Kay 1969). It represents, in fact, an exception in the blue color space; for this reason, several studies have been conducted to demonstrate that linguistic distinctions can have an impact on perceptive discriminations. Thus, lexical discriminations are supposed to increase the perceptive differences since assigning the same word to two different colours reduces the perceptive differences between the two colours.

Some languages, like Catalan, Japanese, Greek and Russian have two basic terms for the two blue hues (light and dark) which identifies the two shades of blue from a perceptual point of view (Giacalone Ramat 1967; Sagaspe et al. 2006; Sandford 2011; Davies and Corbett 1994; Paramei 2005; Thierry et al. 2009a; Athanasopoulos 2009; Kuriki et al. 2017). It seems that this partition is also present in the blue area of the Italian lexicon which linguistically distinguishes between light blue (*azzurro*), assuming the status of BCT (Basic Color Term), and dark blue (*blu*).

Considering that the findings of the major works conducted on color perception have put evidence on the relationship between cognition and linguistic conceptualisation, bilingualism plays a central role for the investigation of the impact of language on categories' representation, as well as on the universality of color foci through the study of the semantic shift of language-specific categories from the first language to the second language or inversely (Ratner 1989; Saunders and van Brakel 1997; Lucy 1997; Pavlenko

2005; Kay, Berlin, and Merrifield 1991; Kay et al. 1997). In fact, cognitive representation of color can be affected by the knowledge of two, or more, languages that differ in the linguistic coding of the colour space, showing how dissimilar categories are represented in the bilingual mind.

Focusing on the study of the basicness of the two Italian blue terms *blu* and *azzurro*, we will analyse, in a contrastive approach, whether there currently exists differences in French and Italian monolingual speakers in the way they perceive colours falling in the blue spectrum, according to their different linguistic partitioning of the color space (French *bleu* vs. Italian *blu* and *azzurro*). French is, in fact, one of those languages which lack the linguistic distinction between light blue hues and dark blue hues, which we find in Italian. Our findings will put additional evidence on the assumption that Italian has twelve BCTs (Basic Colour Terms) and that *azzurro* names a specific independent region of the blue spectrum, corresponding to lighter hues, that in French falls under the same color word as for dark blue hues: *bleu*.

Moreover, this PhD project intends to investigate the consequences of bilingualism on cognitive processes and perception of color categories, trying to shed light on the underlying mechanisms of new categories learning, which can restructure the bilingual mind. When the two bilingual's linguistic systems partition the color space differently, as in the case of French-Italian bilinguals, color categories of the mother tongue, as well as color foci and category boundaries, can be modulated by the lexical distinctions of the second language, with a direct impact on color perception.

Through two main behavioural experiments and three groups of participants (French monolinguals, Italian monolinguals and French-Italian bilinguals), we aim to empirically attest that color semantics is one of the main domains for studying the mechanisms of cross-linguistic variations and that linguistic labeling has an influence on perceptual mechanisms in visual colours, notably in the semantics of blue.

The bilingual group under investigation will allow us to put evidence on the real existence of a perceptual distinction affected by linguistic marks, since color representation will be

determined by L2 (second language) blue categorisation. This would indicate that learning a different color vocabulary may cause shifts towards language-specific patterns, even in languages typologically similar. As a consequence, conceptual representation is not fixed by the L1 (first language), but pre-existing L1 properties can change with the acquisition of new L2 specific features, producing a cognitive reorganization.

In fact, in our case, since the L1 color cognitive representation of blue is affected by the L2 dark and light blue categories, French-Italian bilinguals adopt the Italian blue linguistic partitioning of color space both in French tasks and in fully perceptual non-linguistic tasks. All these factors also determine the degree of impact of bilingualism on color cognition.

This thesis is organized in five main parts: we will present the theoretical background of our research; then a whole section is dedicated to the experimental design, describing the methodological protocol with our objectives and hypotheses; in the fourth part the experimental results are discussed in detail, in perspective to future directions. The last part of the manuscript is consecrated to general conclusions.

The section about the state of art is composed of two chapters. The first chapter starts with some information about the anatomy of the human eye for the understanding of the color vision processes. After the presentation of some of the most relevant color systems, we discuss the two main theories about color naming and categorisation: the relativism versus the universalism, mentioning their evolutionary hypotheses, as well as the critics addressed to each of them. The last part of the chapter is dedicated to the blue color which is analysed from a lexical and a perceptual point of view; research on the blue semantics is mentioned as models at the basis of the current study.

The second chapter of the first section is, on the contrary, consecrated to bilingualism: we try to give a global portrait of the bilingual experience, explaining the different theoretical views and characteristics defining it. Through a contrastive approach between monolinguals and bilinguals, we display the theories on language acquisition and the variables which have an impact on language learning, like the question of the critical age. Information about the connection between bilingualism and cognition are presented in

the second part of this chapter: the bilingual advantage theory, with the description of some models of bilingual language processing, and the bilingual disadvantages are put in contrast.

The third section is composed of one chapter completely dedicated to the description of the experimental protocol: we introduce the present study, with our hypotheses and scientific objectives, defining the two experiments used for our behavioural analysis. The material and design of the Color Word Stroop Task and the Speeded Color Discrimination Task are explained and detailed, as well as the participants' characteristics of our three experimental groups and the data collection.

The fourth section of this manuscript is made of two chapters (chapter 4 and 5): in the first one, we reported all the experimental results, whereas in the second one we present the limits of the present study and some future possible directions. Chapter 4 represents the heart of this thesis since we resume all the data analyses and the statistical results obtained for each experiment in within-subjects and between-subjects comparisons. The expected and unexpected results are compared with our original hypotheses, which have only partly been validated.

In the last section we find global conclusions about the entire PhD project, from the definition of the topic to the future research perspectives, followed by the bibliography and the annexes, where additional material about our experimental protocol is provided (e.g. participants' reports and supplementary features, specific charts, tables and graphs of our experiments' results).

PART I: The State of the Art

Chapter 1: From the Physiology of Color Perception to Color Naming

Introduction

Color is one of the main features to detect and identify objects and reality.

Several studies (Martinovic, Gruber, and Mueller 2009; Spence et al. 2006; Gegenfurtner and Rieger 2000) have demonstrated the crucial role of color in the recognition and visual memorization of artificial and natural images. For this reason, the human visual system has evolved during the centuries and constantly adapts in order to perceive variations in objects' colours. Researchers of different domains have discussed for a long time about the nature of color, questioning whether it is an interpretation of the mind or a characteristic of the external world. Divergent perspectives have highlighted the mind's important role in color detection (Zeki 1999) and, at the same time, the influence of physical reality.

The conclusions have shown that color is not a physical intrinsic property of the world, but it is the perception of the energy emitted by the objects processed by both the brain and the human visual system which, in turn, allow us to charge this energy with specific colours (Pascale 2003). Light radiation induces only some specific chromatic sensations. Thus, it has no color.

Since color perception depends on psychophysical processes, it is described by three attributes (hue, saturation and brightness) and two opponent neural channels (red/green and blue/yellow). Color categorization is, in fact, related to neural processes implemented in the brain connected to perception and language (Siuda-Krzywicka et al. 2019). The relations between color categories and perception and between color categories and language have been one of the main subjects of study in the debates about the dependence or independence of language and concepts (Jraissati 2009). If color perception has been studied in non-human animals and preverbal infants in order to analyse the involvement or the absence of language processing in color categorisation, color naming has been the central point of the debate between universalism and relativism, respectively supported by the Sapir and Whorf's hypothesis and the Berlin and Kay's theory.

In this chapter we will consider color from its psychological, perceptual, physical and linguistic point of view, showing how perception, categorization and cross-linguistic naming are strictly linked and work together in the visual mechanisms. The first section is dedicated to the description of the human eye's structure and the physiological basis of color vision in humans (photoreceptors, cones, rods and human trichromaticity); in the second section we will present the mechanisms connected to the color vision and perception, as well as the three color values describing color (hue, brightness and saturation), and finally the systems which have been developed to identify colours through specific properties (e.g. the Munsell system and the OSA system) and color spaces (CIE, RGB, CIE lab).

In the third section we will discuss color categorization and color naming. Starting from the Basic Color Terms Theory (BCTT) of Berlin and Kay (Berlin and Kay 1969) in opposition to the relativistic perspective of Sapir and Whorf for which perception and color categorization are determined by language, we will consider the hypothesis of the eleven basic color categories and their cross-linguistic variations.

The last section is totally dedicated to the blue color and its uniqueness: since the partition of the blue spectrum represents an exception in various languages, including Italian, we will present some studies on the Russian, Japanese, Greek and Italian color lexicon, trying to find some possible explanations from a semantic and perceptual point of view, useful for our research, too.

The chapter will end with some global conclusions about color perception and linguistic categorisation.

1.1 The human eye's perception

Starting with the assumption that color vision is an illusion and the color we see in the external world is created by neural programs which project it outside, color perception is strictly linked to the perception of forms facilitating the detection of objects' borders (Gegenfurtner 2003).

Two properties of light are used to create colours, namely the energy and the wavelength, or the frequency of vibration. Research on the physiology of color vision has identified the neural circuits underlying the perception of colours and the subjective impressions of color, demonstrating that the color of objects does not change under different viewpoints since the light reflected by the object entering the eye rests the same.

One of the main aspects is that light conditions can change during the day and during different periods of the year or in artificial lighting conditions (Gegenfurtner 2003). However, our color perception of objects and reality do not change, rather it remains solid and permanent in time, as claimed by Brainard (Brainard and Radonjic 2004; Xiao 2016) and Kendel, Schwartz and Jessel (2000). This is possible through the visual mechanism called *chromatic constancy* (Hurlbert 1998; Werner 2014; Kingdom, Angelucci, and Clifford 2014; Ungerer and Schmid 2013): based on the interaction of different neural processes, it allows humans to confide in color appearances for the recognition of objects, without taking into account variations on light conditions. However, the Adelson's Checker-Shadow Illusion seems to contrast this phenomenon: the inferences made by our visual system led to false conclusions caused by previous experience of our perceived lightning conditions. In its experiment, in fact, the contrastive illusion is created by the juxtaposition of the same color in two different lightning contexts: our brain will perceive one of them lighter than the other when the shadow falls across the checkerboard.

Therefore, the human eye is composed of different areas, each of them playing an important role for the proper functioning of the visual system which, in turn, is divided into three levels (low-level, mid-level and high-level) in the processing of information.

1.1.1 The structure of the eye

The ability and the perception to perceive and distinguish different colours is mediated by various mechanisms occurring both in the retina and the brain.

To better understand how color vision functions, it seems useful to briefly remind how the eye is structured from an anatomical point of view (Figure 1). The eyeball, a spherical ball of about 2.5 cm, a skeletal structure allocated in the orbital cavity which contains and protects it, is composed of three main layers. The most external one is formed by the sclera and the cornea, in the layer of the middle (the uvea) we find the ciliary body, the crystalline lens and the choroid; whereas, the most internal layer is occupied by the retina (Kolb 1991; 2011). The posterior section of the eyeball is filled for two-thirds by the vitreous body, between the lens and the retina, which is a clear gelatinous mass allowing the transition of the light.

The sclera, a fibrous, opaque and resistant membrane, is the white part of the eye that we can see and provides protection; on the other hand, the cornea is a transparent structure covering the iris, the pupil and the anterior chamber, furnishing most of the optical power to the eye since it let light rays enter the eye and converge them.

Proceeding through the middle of the eye, we find the uvea, a tissue membrane interposed between the sclera and the retina: it is composed of the iris, the ciliary body and the choroid. The iris is the pigmented tissue which gives the colour to our eyes and constantly controls the light entering the eye, adapting and varying in size depending on light changes. It has a central circular opening, the pupil, through which the light passes and enters the eye. The ciliary body is a ring of tissue allocated between the choroids and the iris and is composed of the ciliary muscle, responsible for the lens accommodation, or the natural crystalline lens of the eye, which brings rays of light to focus on the retina (Tovée 2008; 1996). The really central layer of the eye is occupied by the choroid: it is an extremely vascular support which absorbs rays of light, providing nourishment to the most exterior retinal layers.

The most internal membrane of the eyeball is the retina: a light sensitive nerve tissue that converts images coming from the optical system into electrical impulses which will be sent to the brain through the optic nerve, the largest sensory nerve of the eye. In the retina we find a considerable number of neurons, interconnected by synapses, as well as the photoreceptor cells, divided into two types: the rods and the cones, responsible for the conversion of light, or the electromagnetic radiations, into signals stimulating biological processes. We will describe photoreceptors in more detail in the next section of this chapter.

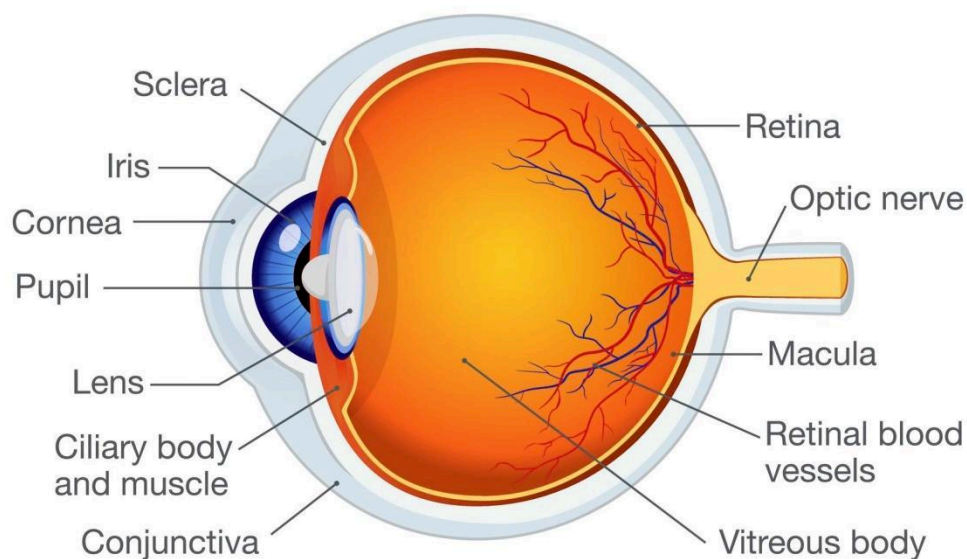


Figure 1: The anatomic structure of the human eye (Helmenstine 2021).

1.1.2 Photoreceptors

Photoreceptors are specialized neuroepithelial cells found in the retina capable of visual phototransduction and specialized in light detection. These nervous cells are sensitive to light waves and are of two types: cones and rods, which are distributed in the retina

uniformly. The capacity to perceive colours is based on the presence of three types of cones responding to specific wavelengths in the field of visible light.

Since the retina is a membrane on the internal surface of the eye composed by three layers of nervous tissue, photoreceptors are in relation with the other cells of the different layers (Figure 2): the ganglion cells and the bipolar cells. Rods and cones are, in fact, perpendicular to the retinal surface and they can incur in variations of their configuration which modulate the release of neurotransmitters. These neurotransmitters play an excitatory or an inhibitory action on the retinal bipolar cells (Kolb 2011; Gouras 2009): they are connected to photoreceptors on one side and to ganglion cells on the other side. At the same time, in response to the receptor transduction, ganglion cells generate some action potentials directed to the central visual system.

Since rods and cones are on the most external layer of the retina, they are excited by the light once it has crossed the internal and medial retinal layers.

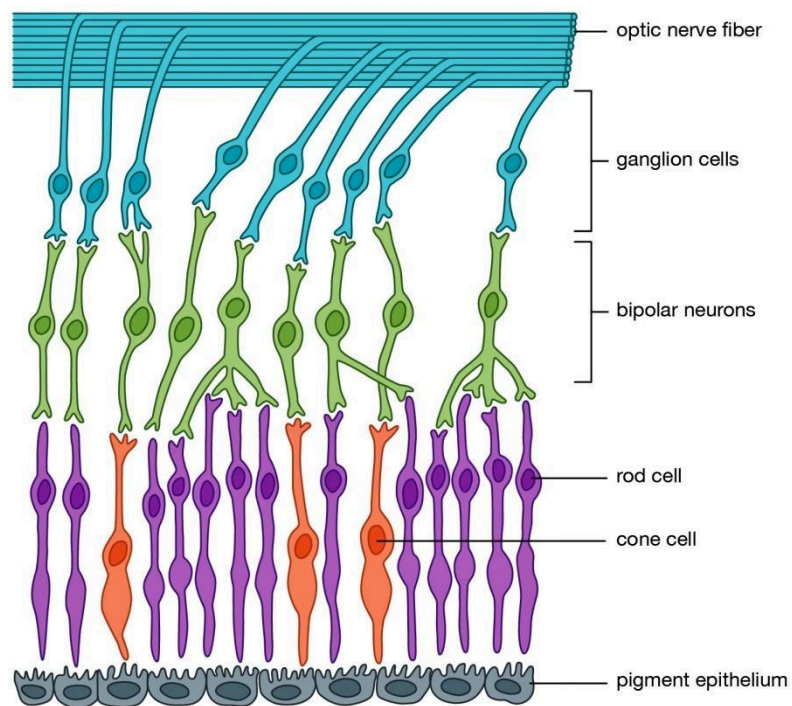


Figure 2: The structure of the retina (*Encyclopædia Britannica, Inc.*).

1.1.2.1 Rods and cones

In photoreceptors there are different kinds of opsins, groups of proteins, which are sensitive to different light stimuli (Figure 3): rods are most sensitive to light in the blue-green spectrum at wavelength peak at about 498 nm, whereas cones can be sensitive to stimuli occurring at nearly 420 nm, as well as to stimuli occurring at nearly 534 nm and to stimuli occurring at nearly 564 nm. The three types of cones are activated in different combinations and proportions depending on the spectral composition of the radiation released by the observed object (Kolb 2011).

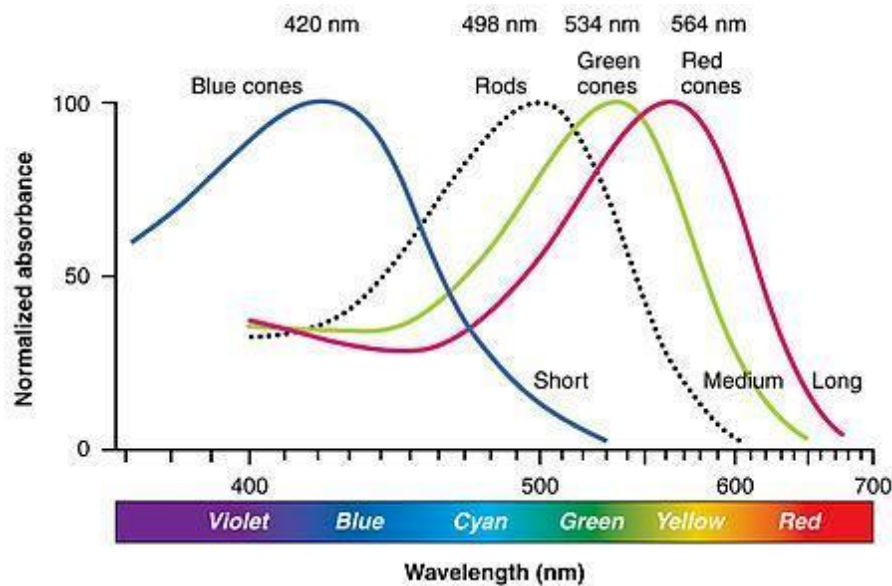


Figure 3: The Spectral Sensitivity: the curve distribution of rods and cones (Santos Silva, Gama, and Gonçalves 2017).

The structural distinctions between cones and rods are strictly linked to functional characteristics.

First of all, rods are around 120 million in the retina: they occupy all the retina with the exception of the fovea. The percentage of the rods increases with the raise of the distance

from the fovea, with a maximal pick at the extreme retinal periphery. They are slow, more sensitive to conditions of low light and are efficient in the detection of luminance but not color. In fact, they allow us to see during the night since they only react at achromatic vision conditions, characterized by white, black and some grey nuances.

On the other hand, cones are 6 million in the retina with a higher concentration on the fovea, which is the location of the vision. In fact, they are responsible for the central vision, allowing the vision of details; they are responsible for the phototypic vision (the daily vision) and are sensitive to artificial sources of light, too.

As mentioned above, cones can be of three types: each of them contains a special pigment which makes it sensitive to different wavelengths of the visible spectrum: the so-called S cones are maximally sensitive to short wavelengths near the blue end of the visual spectrum, the M cones are sensitive to green medium wavelength lights and the L cones are sensitive to long wavelengths at the red end of the visual spectrum (Gouras 2009). The three types of cones are involved in chromatic vision which allows the detection of colours.

In order to perceive all the colours of the visible spectrum, and thus to detect objects with different spectral reflectance, at least two different types of cones are required since their spectra of absorption partially overlap. The greatest and simultaneous stimulation of the three cones provides the perception of white.

1.1.2.2 The Visual Phototransduction

Color perception depends on visual phototransduction which is ensured by the nervous cells. They can, in fact, transform the light entering the eye into chemical and electrical information which will be sent to the brain through the optic nerve. Phototransduction is precisely the process of conversion of the light energy in electric signals through photochemical reactions (Arshavsky and Pugh 2002).

The first step of visual phototransduction is the absorption of the luminous signal by photopigments: each photopigment contains a retinal component, common to all of them,

and an opsin. After the light absorption, the photopigments' molecular structure changes because of light radiations, triggering biochemical reactions which create a nervous stimulation. This stimulation is then transmitted to the retinal cells (bipolar and ganglion cells).

1.1.3 The Human Trichromatic Color Vision

The three types of color receptors with distinct spectra of absorption are responsible for human trichromacy, that is the ability to see different colours due to the presence of three independent channels in interaction during the transmission of color information from the eye to the brain.

The brain could not, in fact, discriminate different colours if it received input from only one type of cones since the response of each cone depends on and varies both with the wavelength and the intensity of light. On the contrary, when the brain receives signals from two or more different cones, it is able to compare them and to determine the intensity and the color of the light entering the eye (Schnapf, Kraft, and Baylor 1987).

The evolution of color vision is deeply linked to the evolution from a bivariate to a trivariate color vision, from primates to the modern man (Daw 1973). Evolutionary history tells us that about 63 million years ago there were only two cone opsins (S and L): a third opsin evolved from the long-wavelength opsin, creating an additional channel for a trichromatic color vision. The absorption of greater spectral reflectance in long wavelength regions is now possible: the original L cone gene duplicated, it becomes the new M cone and a longer L cone is created (Gouras 2009). For this reason, the sensitive peaks of M and L cones are very close.

With the new trichromatic system, a parallel color system occurring in the yellow region of the spectrum appears: the red/green colour system, which was added to the original blue/yellow color system already existing. Trichromacy, thus, provoked an increase in the

repertoire of perceived colours, as well as an increase in the power of colour contrast in the visible spectrum to detect objects.

It is currently estimated that humans can distinguish up to ten million different colours (Leong 2013).

An alternative to the trichromatic theory, firstly formulated by Young and Helmholtz (Helmholtz and Southall 1962), was proposed by Hering (1878; 1964) who postulated that there exists six primitives, or salient color points in the color space being the basis of color naming, grouped into opponent pairs reflecting human neurophysiology: red-green, yellow-blue and black-white. These opponents were supposed to link perceptual contrasts to neurophysiological mechanisms (Saunders and van Brakel 1997). Hering's theory met great success and had been regularly re-examined: in fact, studies on color opponent cells and chromatic pairs have then been conducted by several researchers, such as Jameson and Hurvich (Hurvich and Jameson 1957), De Valois and colleagues (De Valois and Abramov 1966), Kay and McDaniel (1978), Bornstein (1973; 1975); Ratliff (1976); Zollinger (von Wattenwyl and Zollinger 1979), Miller and Johnson-Laird (1976), and Rosch Heider (1973; 1972). All these contributions have allowed the Hering opponent-colours model to be considered, for a long time, one of the best theories to describe color appearance and representation and early visual processing.

1.2 Colour Vision

The ability to distinguish objects relying on the wavelength of the light they reflect or transmit is called color vision.

Since the colour perception by the human eye is a subjective process, different people can see the same illuminated object or the same source of light differently. Color perception, thus, depends on the context and the background of the perceived object, too.

However, in order to provide accurate and universal methods to analyse and describe the color space based on specified properties, different mathematical models and spatial systems measuring and quantifying colours have been conceived.

As we explained in the previous section, there exists different theories about the connection between the neurophysiological mechanisms and the colors' contrast perception since color perception is determined by both physical processes and psychological mechanisms. Consequently, the visual input, the chromatic spectra and the wavelengths of light are three factors which are integrated into the human experience of colours. In the next paragraphs we will detail the functioning and the interaction between these two kinds of processes.

1.2.1 Color perception: physical and psychological processes

Physical and psychological variables are combined with color attributes in the processing of color perception. The physical stimulus perceived by the observer is the light reflected or transmitted into the eye by objects and reality; this input becomes an output with the color experiences of the observer who sees the objects or the reality.

The physical variables (e.g. the spectral distribution of the stimulus, the radiance and the wavelength) are, thus, converted into psychophysical variables, like luminance and purity (the degree of a color to be made of two or more colours mixed together), and the perceived color is described through the six color attributes: brightness, lightness, hue, saturation, chroma and colorfulness (Pridmore and Melgosa 2015).

Since color does not exist in nature, any description of it is not mentioned in the definition of the physical features of light; rather, it becomes relevant when the observer experiences it in a completely subjective way. Colors cannot, in fact, exist autonomously of the observer, whereas light stimuli of different wavelengths can.

1.2.2 Color Attributes and psychophysical variables

One of the main purposes of color science studies is to understand the relation between the physical and the psychophysical stimuli and the perception of colours functions, or how the physical and psychological color variables influence perceived colours and inversely (Pridmore and Melgosa 2015). Thus, the classification of specific phenomena, like the perceptual-psychological effects of physical input, could allow the prediction of every perceived color through a set of variables.

The three conventional psychophysical variables are luminance, complementary wavelength and purity (Wyszecki and Stiles 1982), whereas the color attributes which interact with the psychophysical ones are six in total: hue, chroma, lightness, brightness, saturation and colorfulness. These dimensions define all nuances of perceived color; however, since color is three dimensional, it can only be definable through three variables. For this reason, a single variable or dimension can have multiple perceptions (e.g. lightness may be perceived as lightness or brightness), but only one variant can be perceived at one time considering that color description is limited to three variables (Pridmore 2007).

The interactions between the three psychophysical variables and the six color attributes generate eighteen possible effects which define the influence of each variable on each attribute, as well as the impact of the psychophysical variables on color appearance. In fact, any feature of color appearance cannot be considered separately to the others: changes in one psychophysical variable simultaneously affect the perception of color attributes. Thus, one dimension cannot vary without changing the others (Arend 1993).

The six color attributes are characterized from a perceptual point of view since they can be defined as the way in which humans perceive an aspect of lights and objects' physical properties; they are, in fact, attributes of the visual perception. We provide in this section a brief description of each of them (Briggs 2007):

- Hue: the pure color perceived by the human visual system related to a limited spectrum inside the visible spectrum. The CIE technically defined it as the

“attribute of a visual perception according to which an area appears to be similar to one of the colours: red, yellow, green, and blue, or to a combination of adjacent pairs of these colours considered in a closed ring” (CIE 2011, 17-542).

- Brightness: the visual perception of the light’s transmission or reflection; it is, thus, a subjective property of the observed object or source of light. The CIE technically defined it as “the attribute of a visual perception according to which an area appears to emit, or reflect, more or less light” (CIE 2011 ,17-111).
- Lightness: the representation of the human perception of a color’s brightness. The CIE technically defined it as "the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting" (CIE 2011, 17-680).
- Colorfulness: the perceptual characteristic to perceive the color of an object or a surface more or less multi-coloured. Colorfulness is the proportion of the total amount of monochromatic light, following the principle that each color can be analysed by adding or removing a certain amount of monochromatic light to the white light (Fairchild 2002; 2013). The CIE technically defined it as the “attribute of a visual perception according to which the perceived color of an area appears to be more or less chromatic” (CIE 2011, 17-233).
- Chroma: the chromatic strength of an object or a surface color (Fairchild, 2013). The CIE technically defined it as “the colourfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting”(CIE 2011, 17-139).
- Saturation: the chromatic intensity in the relation of the chroma with the whitishness. It depends on both the light intensity and the spectrum of the light wavelengths on which it is distributed. It is technically defined by the CIE as the “colourfulness of an area judged in proportion to its brightness” (CIE 2011, 17-1136).

As mentioned above, the interaction of these six color attributes with the three psychophysical attributes allows the description and the prediction of colours. Numerous color-order systems use them, employing three-dimensional color attributes for most purposes; the interrelations between formulas and theoretical methods in color spaces permit numerical color measurements, analysis of color differences and color matching and color mixture predictions (Briggs 2007; Albers 1975).

1.2.3 Color Order Systems

The need for ordering and classifying colours in models goes back to ancient times, providing different organizations following a specific logic. These models have assumed diverse shapes: chromatic circles, linear scales, triangles, solids (cones, spheres, cubes, pyramids). Their main purpose was always to categorize colours in rational plans, arranging color stimuli and chromatic perceptions based on defined rules (Nemcsics and Caivano 2015).

The first color systems were linear organizations of colours, usually just lists of color names or simple scales without any graphic representations, or triangular or circular two-dimensional diagrams. One of the precursors of the modern chromaticity diagrams is the Isaac Newton's one: in the study of the physical basis of color, he distinguished seven colours in the color spectrum produced by the light diffused through a prism, which he graphically represented as a circle divided in seven points, converging to a common center (the white light) or the center of gravity. His two-dimensional circle was constructed on the additive components for color mixing: colours are evoked by different combinations of coloured rays (red, orange, yellow, green, blue, indigo and violet rays) having the same centre but which cannot be distinctly captured by the human visual system (Briggs 2007; Nemcsics and Caivano 2015). Newton had, in fact, already understood that there exists a psychological sensation of colours and the physical light rays "producing" colours (Shapiro 1984; 1994).

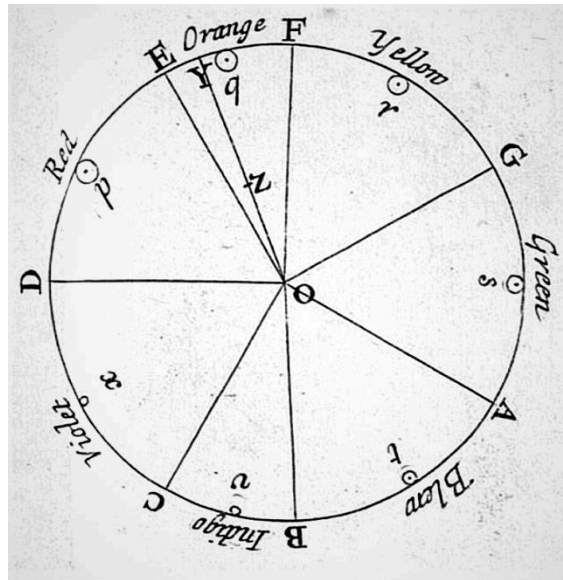


Figure 4: Newton's color circle in *Opticks* (Newton 1952).

Other color systems have been constructed on trichromatic models based on the three wavelengths components of light: a set of three numbers, called tristimulus values, specifies the color of any light from a psychophysical point of view, as the human visual system detects it (Sivik 1974). Moreover, these tristimulus values use a standard human observer, mathematically set, in order to contrast the individual variations in color perception among individuals (Briggs 2007; Nemcsics and Caivano 2015).

One of these systems using tristimulus values for specifying the psychophysical color of a light stimulus is the Munsell Color System. We will present it and the OSA-UCS Model (Optical Society of America Uniform Color Scales) in the following section because they have primarily considered the human perception features in the definition of their parameters.

The last part of this section is dedicated to the description of the RGB Color Model for being one of most common additive color models still used worldwide.

1.2.3.1 The Munsell Color System

Tristimulus values, or XYZ values, psychophysically specify the color of an object or a surface through the reflected light under specific daylight conditions, which is a combination of short, middle and long wavelengths (Briggs 2007).

However, these three XYZ values do not individually correspond to the three wavelength components (Evans 1974) and can vary according to the variations in viewing conditions. They can, in contrast, be converted to perceived color attributes. This conversion is possible only if a standard viewing set is determined in advance, like in the Munsell system which uses specific forms of daylight illumination in order to describe the perceived colours as they would be intrinsic attributes of the observed object (Kuehni 2001).

The Munsell Color System is a color space which attempts to represent colours on the basis of three properties: hue, chroma and value, or lightness. It has been the first model to be representative of the human subjective perceptual colours space (Cleland 1921; Jraissati 2009) and to separate the three properties in independent dimensions, representing them in a three-dimensional space. In fact, his model is based on the visual response to color of a subjective observer (Cleland 1921). For this reason, it has been the referential model for a long time and only recently replaced by modern models, such as the CIELAB model.

In 1913, the teacher and painter Albert H. Munsell published the “Atlas of the Munsell Color System”, a sort of tractate where he describes a sophisticated color model based on subjective impressions (Munsell 1913). As mentioned above, he attributes three dimensions to color: for him, the hue is the chromatic distinctive quality of an object or a surface where colours differentiate; the value is the color luminance (the lightness or darkness of the color) and the saturation is the color intensity, or the degree of distance from gray or white.

Munsell three-dimensional model is a sort of spherical solid where the hue is represented by letters (R for red, B for blue, G for green, and so on) and between the primary colours are placed intermediate colours, always described by letters (e.g. GY corresponds to

green-yellow) (Jraissati 2009; Newhall, Nickerson, and Judd 1943). The hue dimension is modelled by horizontal circular plans, on the equator of the sphere there are five main colours (Red, Yellow, Green, Blue et Purple) considered by Munsell as the fundamental ones. The spacing between these colours is equidistant for a total of 10 hues partitioning the circle, five of which corresponding to the primary colours and the other five corresponding to intermediate colours (Figure 5).

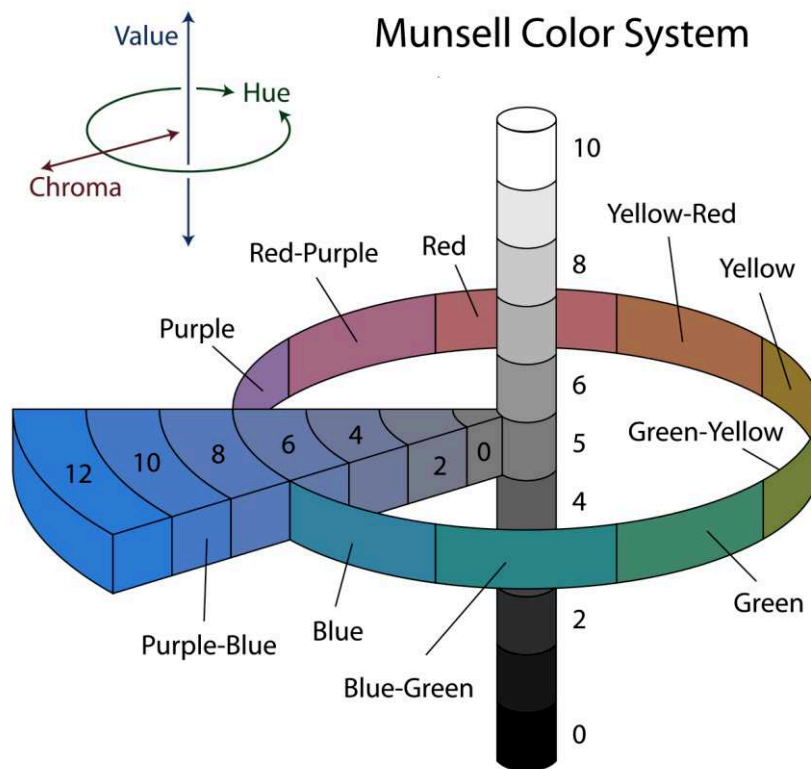


Figure 5: The three-dimensional Munsell Color System (Wikipedia).

Each hue is shared in four degrees of shades (degrees 2,5; 5; 7,5 and 10): thus, there are forty degrees of hue, ten degrees of value and eight degrees of chroma (saturation). These

three dimensions define the Munsell notation: for example, in 7PB 5/1, 7 Purple-Blue is the hue, the value is 5 and the chroma is 1 (Munsell 1905).

To highlight the individual character of each color in each dimension, Munsell represents his three-dimensional model with a tree, too (Indow and Kanazawa 1960). As we can see in figure 6, each branch of the tree is a hue (Red (R), Red-Purple (RP), Purple (P), Purple-Blue (PB), Blue (B), Blue-Green (BG), Green (G), Green-Yellow (GY), Yellow-Red (TR), Yellow (Y)), perpendicular to the trunk, representing the chromatic axis or the value. In the Munsell tree, values range from 0 on the top (pure black) to 10 on the bottom (pure white). The chroma scale is finally represented with extended branches from the center of the tree to outside on the horizontal plan, moving from low to high chroma (Munsell 1905).

This model put in evidence the intrinsic asymmetry of the system, as well as the equidistance between adjacent colours in the three dimensions: each color is, in fact, equidistant from its two neighbour colours in hue, value and chroma, allowing the description of a color on the basis of the relation between the chromatic perception and the physical features of the stimulus (Munsell 1905; Indow 1988).

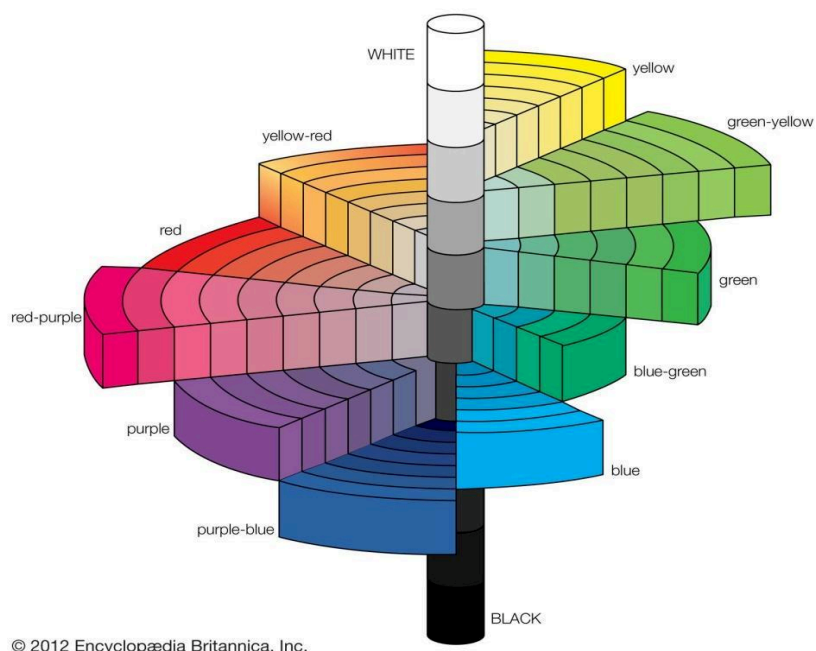


Figure 6: The Munsell Color Tree, taken from *Encyclopædia Britannica*, (Encyclopedia Britannica 2012)

1.2.3.2 The OSA-UCS Color System

The other color system we aim to briefly present in this section is the OSA-UCS.

The need of a new model describing the color spacing uniformly led the Optical Society of America to the creation of a scientific committee in charge of a model where uniformity matched in all directions (BabelColor: The Optical Society of America Uniform Color Scales - Pascale 2009). The Munsell color system, which was the most used one, was not, in fact, highly accurate: one step in the hue, one step in the value and one step in the chroma did not certainly represent the same size in the perceptual differences. The distance between two colours on the chromatic diagram did not correspond to the perceptual differences (Nickerson 1979).

The UCS committee worked on a new color system from 1947 to 1977. They finally constructed a model describing a uniform color spacing through three perpendicular dimensions. The geometry chosen was a rhombohedral lattice based on a cuboctahedron (figure 7) since it was a solid where the 12 vertices are at an equal distance from both a center point and each of the neighbouring points (Kuehni 2012). Each color is, thus, equally distant from the 12 other colours from a perceptual point of view.

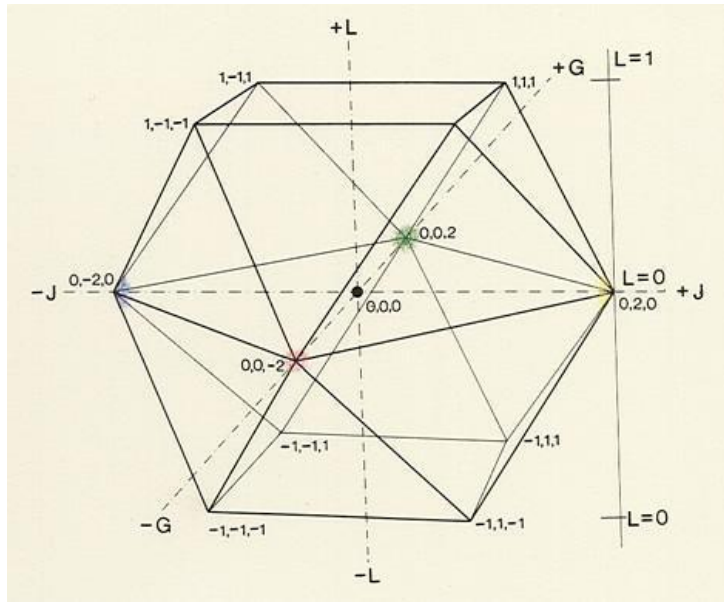


Figure 7: The Cuboctahedron representing the OSA-UCS Color System (Optical Society of America, 1960).

The three coordinate values defining colors' notation are the lightness (L), the yellow/blue opponent dimension (j) and the green/red opponent dimension (g) (Boynton et al. 1989; Nickerson 1979).

The lightness is a scalar value varying vertically which central plane corresponds to the neutral middle grey used for the UCS experiments ($L = 0$); the j value is an horizontal coordinate which runs from the more yellowish nuance (positive values) to the more blueish nuance (negative values); the g values is another horizontal coordinate varying from a positive value (the more greenish) to a negative value corresponding to the more reddish. The j coordinate is perpendicular to the L dimension, whereas the g coordinate is perpendicular to both the L and the j dimensions (Nickerson 1979; MacAdam 1974; BabelColor: The Optical Society of America Uniform Color Scales - Pascale 2009).

1.2.3.3 The RGB Color Model

The RGB (Red- Green- Blue) Color Model is a system to represent color based on color mixture, not on human perception. For this reason, it is one of the most employed models for the description and the reproduction of color chromaticity in camera displays, electronic devices, like television, video projectors and computers, and photography (Hunt 2004; Hirsch 2004).

It is an additive color model since red, green and blue light are mixed to create a more extended collection of colours (figure 8); red, green and blue are defined as the additive primary colours. Thus, to form a color with the RGB model we need to superimpose the three light rays, one for each color, by reflection or by emission: each light ray can have a specific intensity, ranging from the strongest intensity to the lowest intensity (Hirsch 2004).

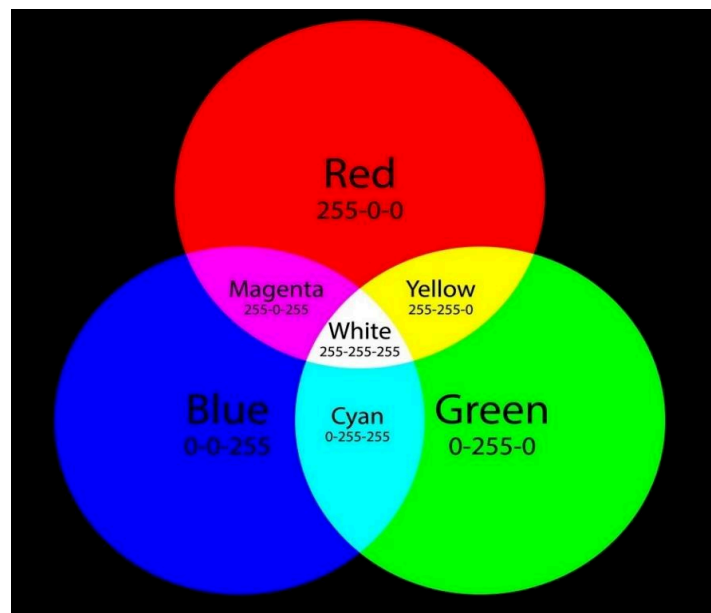


Figure 8: The additive RGB Color Model.

Mixing the three components can produce various results: when the three components have the same intensities, we obtain grey; whereas when the three intensities are different, the product is a coloured hue whose saturation depends on the difference of

the strongest and lowest intensity values of the primary colours. When one of the three components has the strongest intensity, the hue of the color is near to the corresponding primary color (more red, more blue or greener); in contrast, when two of the three components have the same strongest intensity, we obtain a secondary color (cyan, magenta or yellow). Thus, a secondary color is properly the sum of two primary colours with equal intensities: if we mix red and green, we obtain yellow, if we mix blue and green, we obtain cyan and if we add red to blue, we obtain magenta. Each secondary color has its primary color complements, too: red is the complement of cyan, green is the complement of magenta and blue is the complement of yellow.

Lastly, when the three primary colours are mixed in equal full intensities, we obtain white, whereas when they are mixed at zero intensity, we obtain black (the absence of light).

The geometric three-dimensional coordinates representation is a cube (figure 9) allowing the calculation of RGB colors' proximity and distance: the more they are close, the more they are similar. We find, in fact, on the x-axis the red values, increasing from left to right, on the y-axis the blue values, increasing to the lower right and on the z-axis the green values, increasing from the bottom to the top.

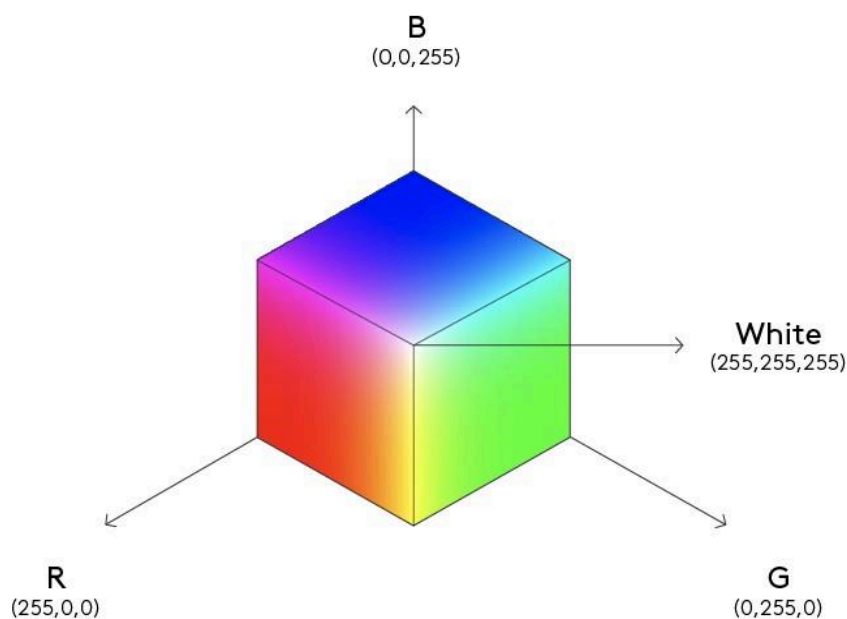


Figure 9: The cube representing the RGB Model with the R, G, B coordinates (Levy, 2022).

1.2.4 Colour Spaces

Color models are abstract systems describing colours represented through mathematical coordinates (Young 1802). However, if color models are not associated with color spaces, they are just color systems, more or less arbitrary, without any conventionally defined color interpretation.

Thus, color spaces are the combination of a color model and a proper mapping function of the corresponding model. They can be based on physical descriptions, like the RGB Color Space, or on human perception, like the CIE 1931 XYZ, and allow color organization and reproduction (Logvinenko et al. 2015).

The two most universal used color spaces, also functioning as reference standards, are the CIEXYZ Color Space and the CIELab Color Space which we will describe in the next paragraphs: their peculiarity is the integration of the human perceptual components in color vision, with the representation of all the possible colours visible by the human eye.

1.2.4.1 The CIE 1932 XYZ Color Space

The International Commission on Illumination, or Commission Internationale de l'Éclairage in French, is an international institution responsible for research and the definition of standards on light, colours and illumination (CIE 1932).

In 1931 the CIE defined for the first time a color space constructed on the combination of the electromagnetic stimuli of the wavelengths in the visible spectrum and the psychophysical color perception in the human color system (Smith and Guild 1931). Moreover, it is based on the tristimulus values as well as on the additive synthesis of the three primary colours.

The tristimulus values XYZ correspond to the humans' trichromacy and its sensitivity to the three types of color rays responding to different wavelengths. The Y parameter designs the luminance of the color, whereas x and y define the chromaticity; thus XYZ values are analogous to the LMS cones' responses even though they do not completely correspond (Guild and Petavel 1931).

Another relevant factor of the CIE 1931 XYZ color space is the integration of a standard observer: the tristimulus values, in fact, depend on the peripheral vision of the observer by reason of the distribution of cones in the eye. This variable has been eliminated by the CIE through the introduction of a standard observer representing the human vision system or, in other words, the average of the chromatic response within a 2° arc inside the fovea, where the color-sensitive cones are believed to be located (Hunt and Pointer 1998; CIE 1932).

In figure 10 the chromaticity diagram of the CIE 1931 color space is illustrated.

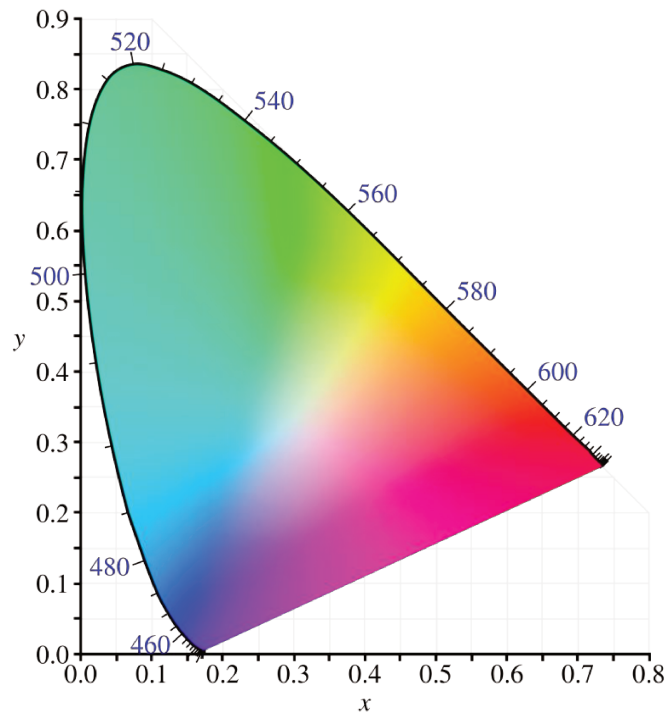


Figure 10: The CIE 1931 Color Space Chromaticity Diagram (Wikipedia).

This tongue-shaped figure represents the color gamut experienced by the human eye in a given spectrum where the light wavelengths are listed in nanometers and the outer curved boundary represents the spectral locus, which corresponds to monochromatic light. The straight line on the lower part is the line of purples. The gamut of the human vision contains all the chromaticities visible by a normal observer: at its center we find the white color, conventionally indicated with the letter “C” (the CIE Illuminant), corresponding to the radiation produced by a white illuminated surface in an average daylight.

The convex shape of the colours gamut is due to the specific functioning of the diagram: for any two given points on the chromaticity diagram, all the colours located on the straight line linking these two points can be formed by mixing them (Hunt and Pointer 1998; Schanda 2007).

1.2.4.2 The CIELAB Color Space

In 1976 the CIE created another color space to further uniform the color differences related to the visual perception; this new model was called the CIELAB color space, or CIE $L^*a^*b^*$. It is a color-opponent space model, where the pairs red/green and blue/yellow are in opposition, and it is based on a referent white (the CIE Standard Illuminant) and calculated on the CIE standard observer (CIE 2004; Durmus 2020).

The CIELAB space covers the entire visible spectrum, or gamut, of the human daylight color perception, representing it in a uniform way. It is calculated on three values: the lightness value L^* and the two chromaticity coordinates a^* and b^* . The L^* value ranges from 0 to 100, where 0 corresponds to black and 100 corresponds to white, on a vertical axis, whereas the a^* axis coincides with the green/red opposition (the $-a$ negative value indicates green and the $+a$ positive value indicates red) and the b^* axis represents the blue/yellow opposition (the $-b$ negative value indicates blue and the $+b$ positive value indicates yellow). These two coordinates have values from -120 to +120 (Schanda 2007).

As shown in figure 11 (Ly et al. 2020) the CIELAB model can be represented with a three-dimensional space where the three coordinates are in nonlinear relations: this absence of linearity corresponds to the nonlinear eye response to the color stimulus. In the CIELAB plane the center is achromatic, or neutral, and the distance from the central axis (L^*) corresponds to the saturation of the color, or chroma (Connolly and Fleiss 1997).

Since this model has been created to perceptually uniform the color space, variations of the $L^*a^*b^*$ components should correlate to changes in the perceived color.

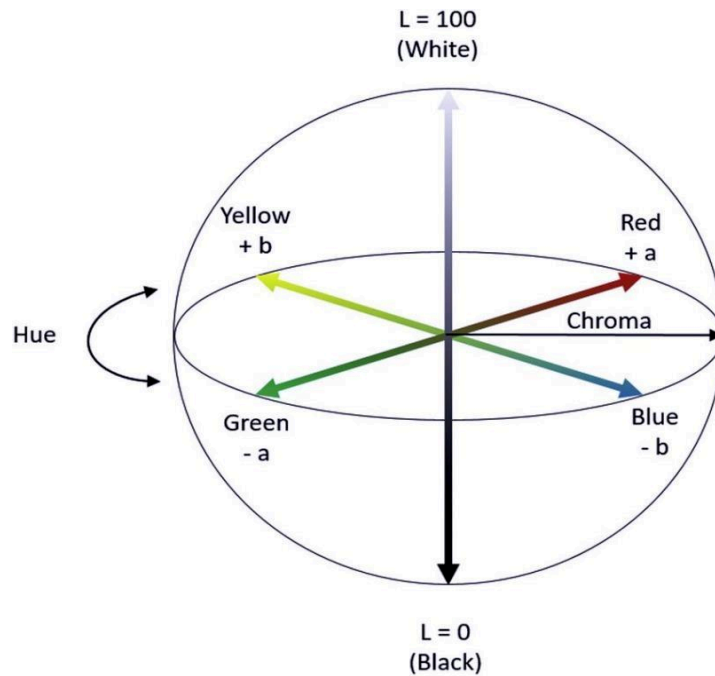


Figure 11: The CIELAB Color Space diagram (Ly et al. 2020).

1.3 Color naming and categorisation

Humans tend by nature to organize all aspects of the world in categories. Even color space is, thus, submitted to this segmentation in order to better identify near and/or similar perceptual hues which, in turn, are designed with linguistic labels.

Since color boundaries and, thus, color lexicon are language-specific, color categorization and color naming are not considered as universal. Color naming is in fact one means to categorize colours (van Kruysbergen, Bosman, and de Weert 1997).

Color categories are the result of several different factors interacting together in a dynamic and flexible way (Bazzanella 2015): the relationship between perceptual categories and the linguistic classification is still undefined or fixed. For this reason, one

of the most discussed domains in the debate between universalism and relativism is the correlation of chromatic lexicon and color categorization (Taylor 2003).

In the third section of this chapter we will present the emergence of color categories and color perception in their relationship with language categorization inside the two main theories on color cross-linguistic variations, notably the Berlin and Kay's Basic Color Terms Theory (Berlin and Kay 1969) and the relativistic approach supported by various scholars (Roberson et al. 2005; Casson 1997; Regier, Kay, and Cook 2005; Wierzbicka 2008).

1.3.1 Color categories: between perception and language

The assumption that perceptual processes are responsible for categorical perception (CP) is shared by several scholars. From this point of view, elements belonging to different categories are better discriminated than those following into the same category (Harnad 1987). However, there is no universal consensus on the perceptual nature of categorical perception: Roberson and Davidoff (2000) for example affirm that CP is rather determined by the recall of linguistic labels stored in the working memory.

Different domains have demonstrated the presence of the Categorical Perception through researches conducted notably on speech perception and production (Liberman et al. 1957; Logan, Lively, and Pisoni 1991) and various aspects of vision: facial expressions and facial actions (Young et al. 1997; Calder et al. 1996; Campbell et al. 1999), faces recognition (Campbell et al. 1997); lines' length perception (Tajfel and Wilkes 1963); perception of simple objects (Newell and Bülhoff 2002).

Effects of categorisation have been detected in color perception, too, in tasks on similarity and dissimilarity judgments (Bornstein and Korda 1984; Laws, Davies, and Andrews 1995; Boynton et al. 1989), memory and recognition (Uchikawa and Shinoda 1996).

Therefore, Categorical Perception, or the discrimination of different categories along a continuous dimension from a perceptual point of view, has been theorized from three main points of view: in literature, we find the naturalistic theory, the labelling theory and

the perceptual change theory. For the first one, supported by researchers like Snowden (2002) and Bornstein (1987), CP is inborn and perceptually mediated: the perceptual representations are discerned in underlying discrimination through inherent perceptual processes. In color perception, for example, children are able to perceptually categorize colours before learning the corresponding color words and they first use a general term for all the nuances of the same color category before differentiating them, in all languages (Bornstein, Kessen, and Weiskopf 1976; Gerhardstein, Renner, and Rovee-Collier 1999; Franklin 2015; Davies and Franklin 2002). However, this theory does not explain how CP variation occurring from one language to another works (Kay and Kempton 1984), nor takes it into account that CP can arise as a result of new categories' learning or contextual information (Goldstone 1994; 1995; Özgen and Davies 2002).

Other researchers, like Harnad, Hanson and Lippa (Harnad, Hanson, and Lubin 1991; Goldstone, Lippa, and Shiffrin 2001) support perceptual change theories, for which the categorisation of a stimulus is caused by representational changes of the stimulus itself. These changes can cause a shift in the stimulus boundaries or can create new perceptual configurations (Schyns and Rodet 1997): CP is, thus, not inherent but acquired, even though perceptually mediated. Experiments with perceptual discriminations practice have shown that category-training improves perceptual performance in the short term but not in the long term (Poggio, Fahle, and Edelman 1992; Goldstone 1994; 1998).

For the third approach, represented by the direct language theories (Rosen and Howell 1987; Fujisaki 2008; Roberson, Davies, and Davidoff 2000; Kay and Kempton 1984), discrimination is determined by comparisons of verbal labels, which help us in judgments of cross-category elements. Cross-category judgments are based on comparisons of perceptual information and verbal labels, whereas within-category judgments are mainly based on perceptual codes. However, one limit of these theories is that differences of linguistic labels do not always correspond to differences in CP, like in the case of cross-linguistic variations between objects' naming and their corresponding representation (Malt et al. 1999).

Some studies reported some results against CP effects with categorisation training (Goldstone, Lippa, and Shiffrin 2001), whereas others, like Roberson, Davies and Davidoff

(2000), attested the presence of a direct effect of language on CP, especially in color categorical perception.

Huttenlocher and his colleagues (Crawford, Huttenlocher, and Engebretson 2000) and Bartlett (1932) finally argued that categorical perception is rather linked to memory processes than perceptual strategies since it is determined by category prototypes and not by verbal labels.

All these different points of views empirically reveal that there is no actual consensus about the nature of the CP processes and experimental results are often dissimilar. A particularly debated point is the role of language in perception, notably in the domain of color categories, where studies on human neural correlates and color categorisation in absence of language have been extremely prosperous.

1.3.1.1 Chromatic categorisation without language

Studies on animals, infants and subjects with brain lesions have shown that color categorisation can also emerge in the absence of linguistic abilities. In fact, color categorisation and perceptual processes might directly interact through attention to the chromatic differences, which are relevant to categorisation, without language involvement.

In this field of study, three main procedures have been developed to identify the respective role of language and perception in color categorisation, as well as their interaction: the first two approaches have analysed color categorisation in young children without language yet (Bornstein, Kessen, and Weiskopf 1976; Catherwood, Crassini, and Freiberg 1990; Franklin et al. 2008; 2005; Ozturk et al. 2013; Franklin and Davies 2004; Skelton et al. 2017) and in animals (Vauclair 2002; Maugard, Marzouki, and Fagot 2013; Freedman et al. 2001; Wright and Cumming 1971; Goldman, Lanson, and Rivera 1991; Jacobs 2018; Vorobyev et al. 1998), whereas the third one has focused on human neural processes related to perception and/or language.

Therefore, these three models have not provided uniform results: their findings are, in fact, diverse and sometimes extremely divergent. Looking globally, we can affirm that a sort of categorical effect in colours is evident in infants and animals, especially for responses in the occipito-temporal regions of the brain. However, this kind of responses, also detected in adult humans, cannot be certainly determined by lexical color categories: thus, the comparison between the three groups is particularly unstable.

Moreover, defining a specific perceptual reference measure in infants and animals is extremely difficult: some studies (Knoblauch, Vital-Durand, and Barbur 2001) have demonstrated, in fact, that infants' colour discrimination differs from adults' colour discrimination both in first and second stages of color representation, even though others (Lindsey and Brown 2014) proved that second stage processes are the same. The first stage corresponds to the reception work of the blue, green and red cones, whereas the second stage corresponds to the color opponency at a neural post-receptor level.

However, the question is still debated: Skelton and his colleagues (2017), for example, affirmed that innate second stage mechanisms define color categories which change throughout life since they are impacted by culture. From this point of view, categorical discrimination is the same in infants and adults. However, the comparison remains complicated since experiments with infants use color samples with larger colours differences than those used in adults' measurements, where the chromatic boundaries are extremely subtle (Skelton et al. 2017). Infants' categorical responses can be linked to reactions to new stimuli, which are salient, attracting infants' attention and gaze, too (Kidd, Piantadosi, and Aslin 2012).

The comparison and the relationship between adult and infant categorisation is, thus, approximative; further research is needed.

On the other hand, in the case of animals the main difficulty is the accuracy of the metric used in the analysis of animals' responses: the model adopted for these experiments (Vorobyev and Osorio 1998) seems to not be accurate in the discrimination of fine colour differences. Moreover, it is essential to take into account that for animals, colours are an integral part of objects: colours are, in fact, important signals for reproduction, warning or hunting (Regan et al. 2001; Osorio and Vorobyev 2008; Cuthill et al. 2017). Color

categorisation can, thus, also be the result of a generalization of pre-existent associations between colours and compensations to new color shades. From that perspective, in animals the color space is partitioned in color categories which are centred on salient color shades, linked to relevant visual stimuli (Siuda-Krzywicka et al. 2019).

In conclusion to this section, we can affirm that future research requires different methodological settings, especially in the control of stimuli, and should consider the link between color categories and objects colours as a possible approach to analyse the origin of color categories. It might, in fact, confirm the developmental continuity in color categorical responses from animals to adult humans.

1.3.1.2 Neural correlates of chromatic categorisation

Color perception is processed in the retina and the thalamus, but other neural regions are also involved in color discrimination, especially the cortex (Conway et al. 2010; Gegenfurtner and Kiper 2003; Gegenfurtner 2003). Although a great amount of studies have shown the distribution of color representation in the cortex (Grill-Spector and Weiner 2014; Wade et al. 2002; Lafer-Sousa, Conway, and Kanwisher 2016; Zeki and Marini 1998) the mechanisms underlying color discrimination, as well as the processing related to colours in these regions, is still unclear (Shepard, Lahlaf, and Eskew 2017; Eskew 2009).

Research on the neural correlates of chromatic categorisation has shown contradictory results since some of them rely on color categorisation to linguistic mechanisms, others to perceptual mechanisms and still others to more general categorical processes. Thus, it is difficult to explain the different findings across studies, since each of them provide information about a particular brain area that can be involved in color categorisation (Kwok et al. 2011; Siok et al. 2009; Bird et al. 2014).

In studies reviewed in the literature, three main issues are recurrent: the limited range of colours stimuli in color categories discrimination, the heterogenous type of behavioural

tasks varying from color naming to mnemonic visual detection (Bird et al. 2014; Brouwer and Heeger 2013; Persichetti et al. 2015), and the possibility to consider color categorisation distinct from language and perception. In the latter case, fMRI neuroimaging studies and experiments on neuropsychological lesions have provided an alternative approach to explain color categorisation: not only language and perception, but also other cognitive processes related to specific cortical areas (regions in the prefrontal cortex), can play an important role in color categorisation. One of them is color attention. According to several researchers (Ralph et al. 2017; Embleton et al. 2010; Brouwer and Heeger 2009; Persichetti et al. 2015), attention may have an impact on category effects in color discrimination (Witzel and Gegenfurtner 2015; Witzel, Olkkonen, and Gegenfurtner 2018; Witzel and Gegenfurtner 2018) or may interact with language (Thierry et al. 2009; Maier and Rasha 2018). Language can, in fact, direct the subject's attention on stimuli which are salient for him/her, like distinctions between language-specific color words.

Moreover, recent studies on the neural processing of color perception (Conway et al. 2018; Witzel and Gegenfurtner 2018) have shown that color categories may be also impacted by the direction of attention during communication, as well as by objects in the natural environment. As for animals, in humans objects' detection is strictly linked to colours: neuroimaging studies (Lafer-Sousa, Conway, and Kanwisher 2016) have detected the implication of visual regions and temporal lobes sensitive to both colours and shapes. Color categories can, thus, result from the interaction of different neural and cognitive abilities (Coutanche and Thompson-Schill 2015; Brouwer and Heeger 2013; Yang et al. 2016; Bird et al. 2014; Persichetti et al. 2015; Ikeda and Osaka 2007; Siok et al. 2009) which allows the representation of an object identity. Accordingly, color categories are not processes in only one single brain area, but most probably they depend on a network of neural regions.

1.3.2 Relativism versus Universalism in color categories

The contrast between color perception and categorisation is one of the major domains of investigation in the debate between universalists and relativists.

On the one hand, the universalist approach, mainly supported by Berlin and Kay (1969) and other specialists (Kay and Regier 2003; Regier, Kay, and Cook 2005), affirms that color categories derive from innate and universal perceptual mechanisms, which do not depend on culture and language. As a consequence, during language acquisition, color words are related to pre-existing perceptual categories directly associated with the visual system (Kay and Regier 2006; Witzel and Gegenfurtner 2018), marking perceptual discontinuity in the color space. However, not all languages mark the same perceptual categories (Pilling and Davies 2004).

On the other hand, we find the linguistic relativistic theory of Sapir and Whorf (Sapir 1929; Whorf 1956, followed by Brown and Lenneberg 1954; Lucy 1992; Gumperz and Levinson 1996 and Slobin 1996 for other linguistic categories, such as event conceptualization, which states that language constructs perception: linguistic chromatic categories, thus, shape perceptual categories. For the Relativist position, the variation in the distribution of linguistic category boundaries determines a variation in the distribution of categorical perception. Categorical perception (CP) in colours is defined as the effect for which the discrimination of colours belonging to different categories is faster and/or more accurate than the discrimination of colours of the same category (Bornstein and Korda 1984; Özgen and Davies 2002). This phenomenon will be explicated more in detail in the following chapters of this thesis.

The presence of CP has been investigated both by the universalist point of view and by the relativistic point of view. Studies following the former theory (Bornstein, Kessen, and Weiskopf 197; Franklin and Davies 2004) have shown that categorical effects are evident in prelinguistic infants by four months of life: when they have familiarized with one color and then we show them a new color, they are attracted by the novel color if it comes from a new adult category and they are indifferent if it is from the same adult category.

In contrast, relativist research has demonstrated that, in adults, CP occurs only when the color boundaries are marked by the speaker's language. Roberson, Davies and Davidoff (2000) (Roberson et al. 2005), for example, tested locutors of Berinmo and Otjihimba in the blue-green boundary since these languages do not mark this color boundary. The results showed no blue-green CP, unlike English speakers, tested as the control group, whose language distinguishes the blue-green color boundary (Roberson, Davies, and Davidoff 2000; Roberson et al. 2005). A similar process has been found in infants for the analysis of language influence: CP is detected in two-years children independently of language, but it appears by four-years children only if the infants' language differentiates the distinction linguistically (Daoutis et al. 2013).

For many years, psychophysical studies and experiments involving different languages and cultures have shown contrasting findings about the interrelation between color perception and categorisation (Elliot, Fairchild, and Franklin 2015; Kay and Regier 2006; Regier and Kay 2009; Witzel and Gegenfurtner 2018). In fact, some of them (Berlin and Kay 1969; Roberson et al. 2005; Roberson, Pak, and Hanley 2008) confirmed the presence of a considerable CP variability in the color lexicon, whereas others attested the existence of constant universal patterns independently of linguistic color space boundaries (Gibson et al. 2017; Kay and Regier 2003; Lindsey and Brown 2014; Lindsey et al. 2016; Regier, Kay, and Cook 2005).

The relationship between perceptual categories and linguistic discrimination is, thus, still unclear. However, if color categories are universal and innate, they could be modified by later experience through the lifespan (Pilling and Davies 2004). Therefore, when a color distinction is marked by a specific language, categorical effects can be reinforced, whereas they can be reduced when a language does not have linguistic categories to discriminate it. This instability of the effects of color category has put perceptual categorisation at the center of the theoretical debate between universalists and relativists about color naming and perception.

1.3.2.1 Color naming and perceptual categorisation in the universalism-relativism debate

In the debate between the universalism in color perception and the language-dependent variability of color naming, a factor that is not always considered is the status of context. Van Kruysbergen, Bosman and de Weerta (1997) insist on this issue to contrast the universal reductionist notion that biological universality corresponds to behavioural universality. For them there are communicational constraints which explain the absence of a universal color lexicon, common to all languages, even though the biological mechanisms underlying human color vision are universal. This hypothesis could explain the reasons why people of the same cultural society can easily communicate about colours and objects' identification.

Since perceptual categorisation functions differently from color naming, it is necessary to analyse the context in which categorisation occurs, notably whether linguistic features are involved or not in the task. The risk is, otherwise, the emergence of the following paradox: perceptual categorisation, or color categorisation without the involvement of language, shows universal features in color discrimination, whereas color naming, or color categorisation shaped by language, shows cross-linguistic and cross-cultural variations.

It seems that context plays a central role. For the authors, these contextual distinctions are central in color categorisation, and they could resolve the above-mentioned paradox: we can accept the presence of a cross-linguistic variation in color naming and color perception, assuming that they are strictly interrelated, without refusing the hypothesis of universality in color perception. Color naming has, in fact, more different constraints than perceptual categorisation since communicational needs put more lexical limitations to allow intercomprehension between speakers within the same socio-cultural environment. For this reason, the color spectrum is arbitrarily divided in categories by each language, both in type and number.

1.3.2.2 Neurolinguistic relativity, color cognition and the online effects of language

Cognitive neuroscience and neurophysiological studies have demonstrated that thought is strictly linked to and influenced by language through categorisation. As Lupyan (2012) suggests, a category's feature is associated with a linguistic label as soon as it is learned, and its activation is modulated by perceptual processes. This relativist model tries to explain both the nature of the mechanisms underlying the language influence on different aspects of cognition and the possibility of a language-independent treatment of thought.

To find evidence that there exists conditions in which language stands alone, dissociated from cognition (memory, attention, perception, executive control, inhibition), it is necessary to analyse the neural activity modulation related to perceptual non-verbal stimuli, without components directed by language strategies (Thierry 2016). However, most experiences testing the Linguistic Relativity Hypothesis have used memory or attentional strategies which are subjected to a direct language influence (Kay and Kempton 1984; Heider 1972; Pilling et al. 2003; Roberson and Davidoff 2000). In the domain of colours, for example, subjects are frequently asked to remember and recognise color patches labelled by color names: in these cases, the naming strategies represent an advantage in the recognition of the target word in the array of available terms. A similar account is used in experiments with the discrimination of cross-category stimuli, when they belong to two different color categories (for example green and red), and within-category stimuli, when they fall under the same color category (e.g., two nuances of purple): in this instance, the naming advantage is unregistered only for languages marking a specific color categorical boundary.

Most of the behavioural studies on Categorical Perception have, in fact, focused their attention on the direct language influence in within-language studies (Brown and Lenneberg 1954) or on new color categories' learning (Ozgen and Davies 2002), whose results supported the hypothesis that during infants' language learning, language shapes color perceptual representations. Nonetheless, categorical effects can also be found in tasks lacking verbal procedure, correlated to an indirect language effect. Indeed, visual search tasks and discrimination tasks of various kinds of stimuli presented simultaneously,

demonstrate a less memory involvement as well as an inferior impact of naming strategies in spite of early pre-attentive stages of visual processing (Pilling et al. 2003; Kawai, Uchikawa, and Ujike 1995; Treisman and Gelade 1980), where some stimuli features seem to come first in perception.

Other tests supporting the Linguistic Relativity Hypothesis (Davies and Corbett 1997, 1998; Roberson, Davies, and Davidoff 2000) have shown differences depending on a linguistic influence, even though there exists a relevant set of studies reporting that performance is mostly guided by universal perceptual processes. Globally, we can, thus, affirm that a stronger dichotomy between universalism and relativism cannot explain the heterogeneity in the experimental findings: if some studies, like those of Rosch-Heider (1972), found universality in color perception independent of language, others, like those of Roberson et al. (2000), revealed relevant language-dependent differences between subjects' groups. The language effect can, in fact, be direct and arise even in tasks where participants mostly engage perceptual strategies (e.g., sorting tasks and triads discrimination tasks) or be indirect, like in search tasks, where naming procedures are not required.

For this reason, neurophysiological studies, like those conducted by Thierry (2016; Thierry et al. 2009), analysed the existence of a possible online access to linguistic representation in behavioural detection tasks, where the subjects have to evaluate color features, recording event-related brain potentials. In fact, EEG signals can collect, over a great number of trials, the brain activity related to a particular stimulus or a specific cognitive process: when variation of electric potentials are not linked to the stimulus presented, they tend to fade into background activity. On the contrary, when these variations are directly related to the stimulus, they are repeated and registered from one trial to another. Thierry and his colleagues (Thierry et al. 2009) notably analysed the vMMN (visual Mismatch Negativity) in groups of speakers whose language marks differently the green-blue category. They concluded that, even from a neurophysiological point of view, there is evidence that a language lexical distinction provokes a greater perceptual discrimination for these speakers, as compared to individuals of languages lacking this distinction. For the authors, this effect is linked to perceptual distinctions settled by

repeated exposure to color words labeling this color contrast, rather than to online activation of linguistic representations.

1.3.3 Berlin and Kay and the Basic Color Terms (BCTs)

The contrast between chromatic perception and color naming has been at the heart of the investigation of the Sapir-Whorf Linguistic Relativity Theory (LRT), which states that cognition is determined by language, defining our perception of the world (Brown and Lenneberg 1954). As we reported in the previous section, this hypothesis has found its opposing part in the universalist postulate proposed by Berlin and Kay (1969) who assumed that there exists similarities across languages in terms of evolution and partition of the color space.

In this section we will present the Basic Color Terms Theory (BCTT) in detail from the seminal studies conducted in 1969 by Berlin and Kay to the more modern versions (1975-1991), relying on Rosch's studies (Rosch 1973) in the domain of experimental psychology. The last part will be dedicated to the criticism addressed to the BCTT.

The Basic Color Terms Theory represents the theoretical background of our research, as well as the starting point of our discussion about the relation between language and perception in color categorisation. As we will explain in the next section, this theory emerged in reaction to the Sapir-Whorf Linguistic Relativity Theory, whose main assumption was that language determines color perception. The BCTT, in contrast, supported the opposite point of view: color perception influences and determines the semantics of colours. The first version of this theory is, in fact, guided by the idea that the human visual mechanisms, especially the low-level of visual processing, govern the way in which we categorize colours and we linguistically refer to colours.

1.3.3.1 From relativism to universalism: the Basic Color Terms Theory

The idea that culture, language and context influence perception is crystallized in the Sapir-Whorf hypothesis, which embodies a school of thought that adopts and develops the whorfian initial idea assuming that “the word is presented in a kaleidoscopic flux of impressions which has to be organized by our minds” (Whorf 1940: 213-14). Therefore, the world is disorganized, not cut in advance following natural boundaries; on the contrary, it is the human being who organizes it in categories with his mental means.

A paradigmatic example of this world's initial disorganization is the phenomenon of color perception. Since color is a continuum defined as a set of wavelengths included between 400 nm and 700 nm, from which our color categories originate? The human impression of discontinuity typical of the color continuum human perception, is it originated by lexicon and the context, or does it derive from some perceptual and cognitive mechanisms common to the entire human species? The first assumption is supported by the relativism view, whereas the second one is supported by universalists.

The field of color perception has been at the center the debate between universalism and relativism for many years because it lies on a physiological determinism as well as on perceptual and cognitive treatments, raising questions like *Are colours like “red”, “green”, “blue” and “yellow” really considered as perceptual universals or are they only a sort of ethnocentric projections of our lexicon? To what extent do they determine our color cognition?*

As Jraissati (2009) affirms, the demonstration of the color categorisation's relativity passes through the cross-linguistic observation of color words. In fact, if color words have different extensions across languages and cultures and if their partitioning of the perceptual space does not correspond, that is because color categorisation is not constrained. On the contrary, if a correspondence in the way in which different lexicons partition the perceptual space exists, then we can conclude that color categorisation is determined.

In 1969, Berlin and Kay in their study “Basic Color Terms” (Berlin and Kay 1969) tried to demonstrate, in opposition to the majority of their precursors (Parsons 1924; Ray 1952; 1953), that color categorisation is constant in cross-linguistic lexicons: it is, thus, constrained.

The universalist argument lies on an experimental approach: they asked some locutors of different languages to furnish a certain number of color terms in absence of stimuli. Then, they presented to these locutors some color stimuli forming a continuum and they asked them to specify the best example of the basic color terms identified in their lexicon based on some defined criteria. Subjects were also asked to track the extension of each term on the continuum.

Berlin and Kay used this protocol for the study of twenty languages: their results showed a form of regularity which contradicted the relativist theory. The authors proposed that there exists a limited number of basic terms, universal and common to all languages and that these color terms emerge in the lexicon in a constrained way, following an evolutionary pattern. This experimental protocol was explicitly borrowed from Lenneberg and Brown (Lenneberg and Roberts 1956) who conducted some experiments to investigate the relationship between language and cognition. However, they did not obtain the same findings, nor did they reach the same conclusions as Berlin and Kay: even though they identified some similarities between the chromatic space partitioning of Zuni, an indigenous language, and English, they observed an important difference: the Zuni lexicon does not have a “basic” term for the English “orange”. In fact, another term categorizes this chromatic region, including nuances corresponding to the English “yellow” and “orange”. Moreover, Lenneberg and Brown found that the Zuni lexicon was in evolution, following a similar partitioning of the English lexicon.

In their study, in addition to the twenty languages directly tested on the field, Berlin and Kay analysed the data coming from other sixty languages: their results all attested to a universalist behaviour. For this reason, the BCTT has become an essential reference in the literature on the relationship between language, culture and cognition.

For their stimuli, Berlin and Kay used the Munsell model, as well as for the notion of basic terms, defining them from a more linguistically point of view. They described a basic color term as a color word with the following characteristics (Berlin and Kay 1969): it is monolexemic, or morphologically simple; is frequent and psychologically salient; it is not an hyponym, or it is not subordinate to another color word (for example, the English *scarlet* is not a basic term since it is a variety of *red*); and its use must not be restricted to a small class of objects.

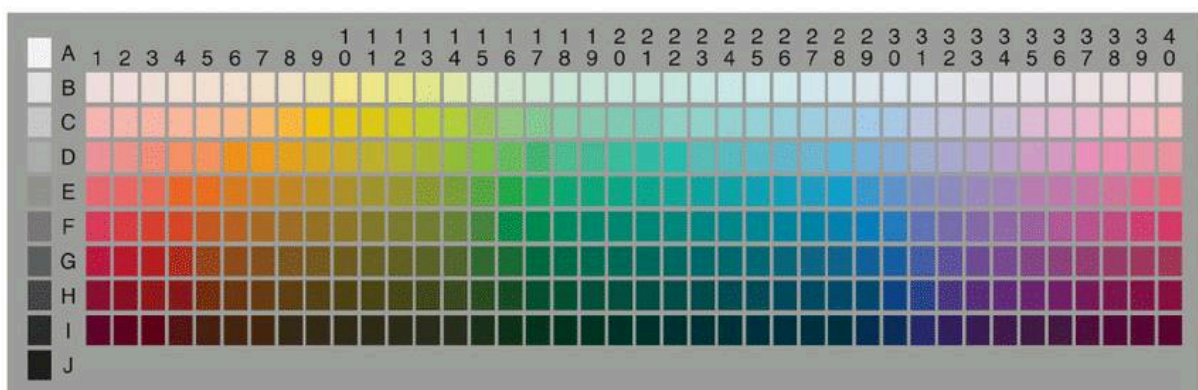


Figure 12: The Munsell Color Chart (Kay and Regier 2003). The array of color chips used by Berlin and Kay in 1969 for their stimuli: on the x-axis we find the saturation value, whereas on the y-axis we find the dimension of lightness.

“Our results... cast doubt on the commonly held belief that each language segments the three-dimensional color continuum arbitrarily and independently of each other language. It appears now that, although different languages encode in their vocabularies different numbers of basic color categories, a total universal inventory of exactly eleven basic color categories exists from which the eleven or fewer basic color terms of any language are always drawn.” (Berlin and Kay 1969: 2)

Berlin and Kay's results involving color words and categories are summarized in the figures below (Figure 13, 14, 15):

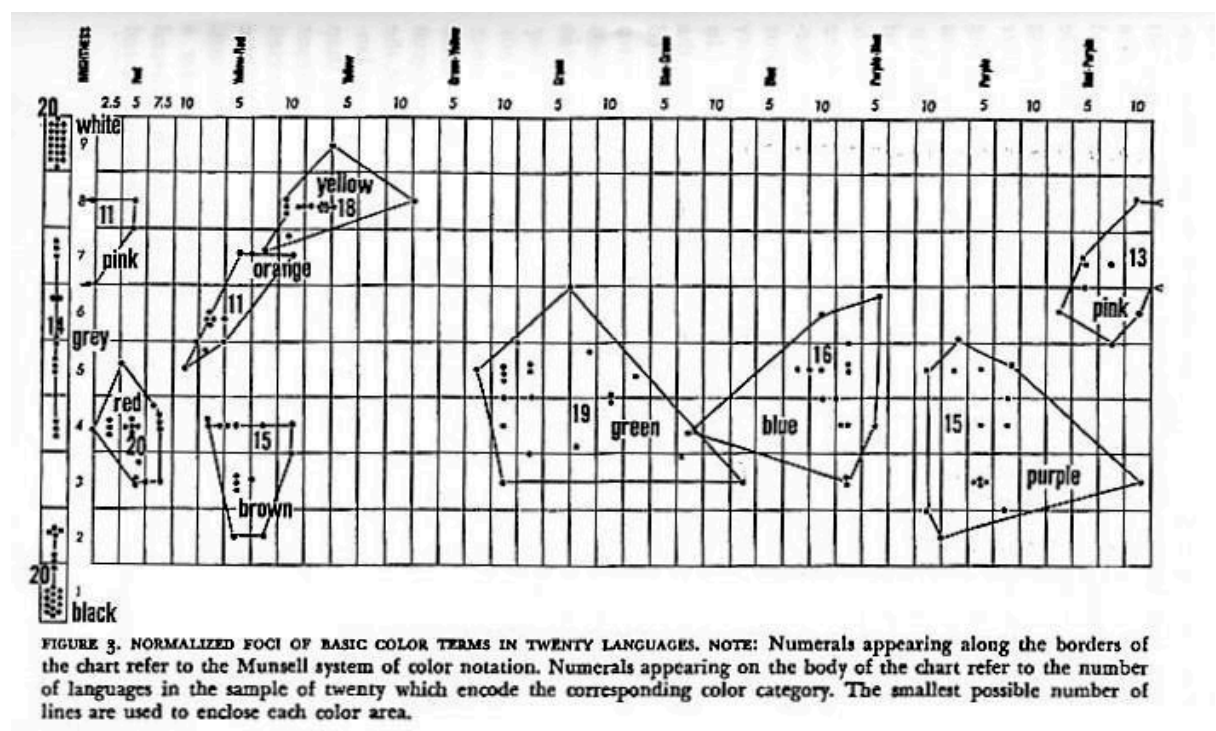


Figure 13: Color foci of basic color terms in twenty languages (Berlin and Kay 1969).

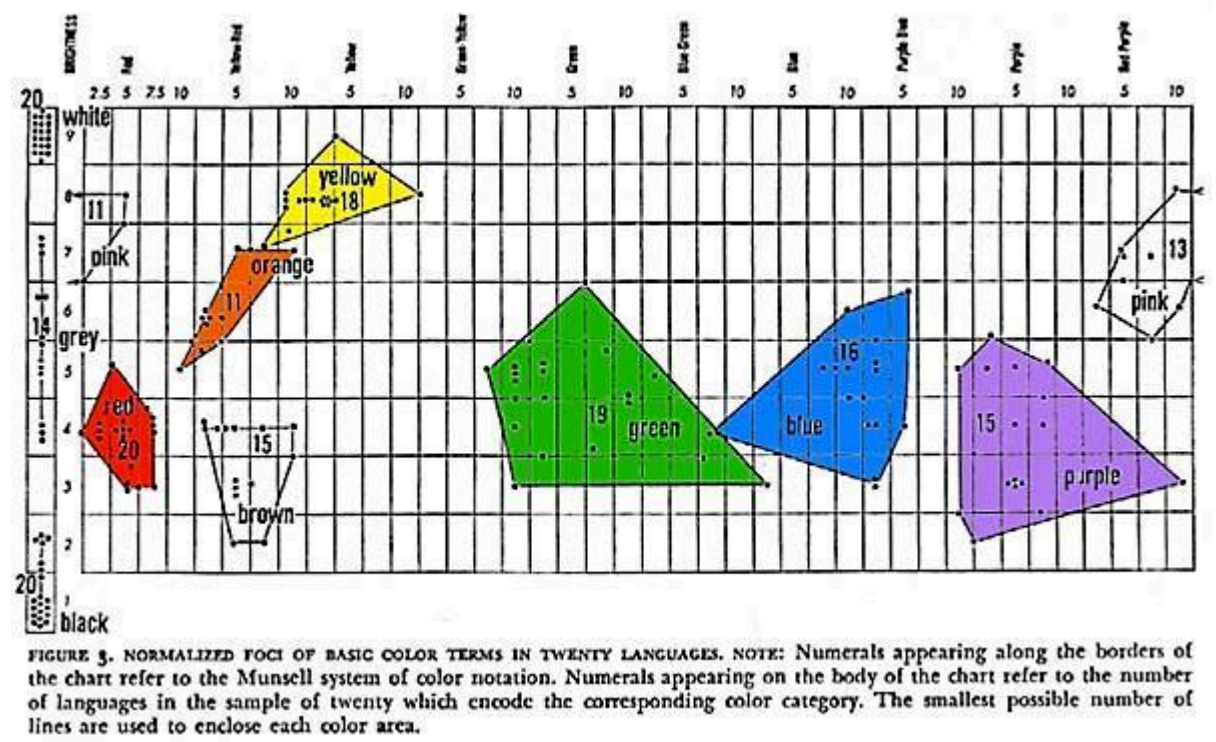


Figure 14: Color foci of basic color terms in twenty languages in colours (Berlin and Kay 1969). The three primary and the three secondary colours of the color wheel are included in the categorical hues.

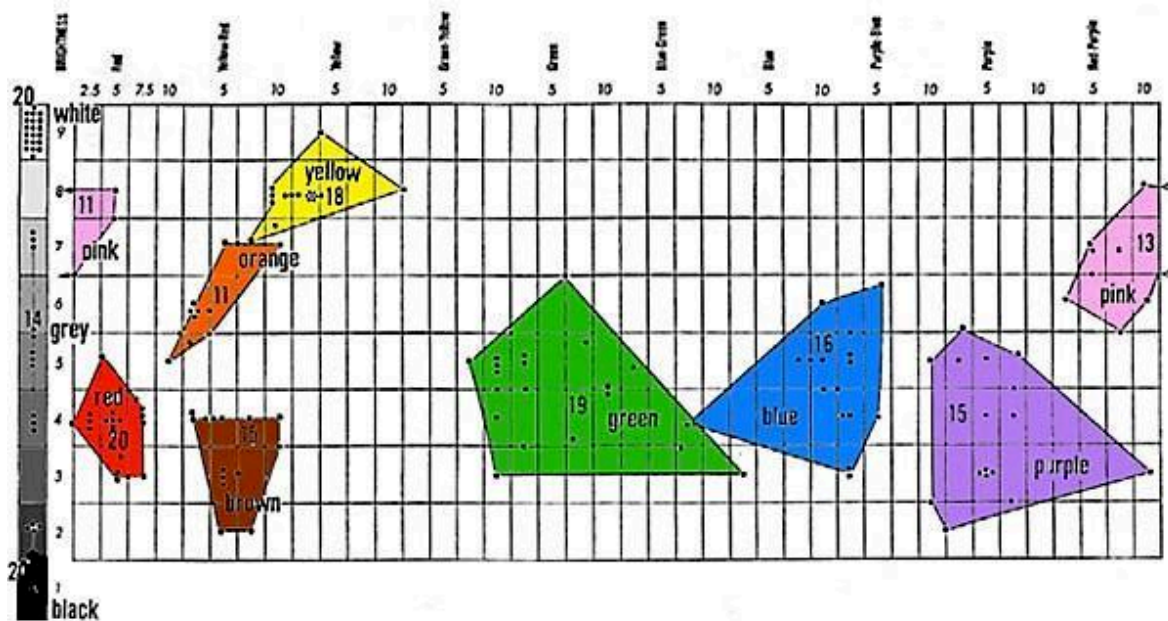


FIGURE 3. NORMALIZED FOCI OF BASIC COLOR TERMS IN TWENTY LANGUAGES. NOTE: Numerals appearing along the borders of the chart refer to the Munsell system of color notation. Numerals appearing on the body of the chart refer to the number of languages in the sample of twenty which encode the corresponding color category. The smallest possible number of lines are used to enclose each color area.

Figure 15: Color foci of basic color terms in twenty languages with additional colours (Berlin and Kay 1969). Two new colours, absent on the color wheel, are added (*pink* and *brown*), as well as the achromatic ones, *black* and *white*, and a *grey* scale.

The notion of evolution is an additional characteristic of the BCTT: it, in fact, justifies the universalist assumption that the evolutionary trajectory of languages partitions the chromatic perceptual space in different ways. For example, a language with four basic terms does not shape the perceptual space in the same way as a language with five basic terms. However, this would not mean that the language with four basic terms will never partition the perceptual space in the same way as the language with five basic terms when a fifth basic color term appears in the lexicon. The difference in the color space partitioning between languages is, thus, validated by the lexicon universal evolution.

To support their universalist argument, Berlin and Kay (1969) proposed two main statements: the first one is the existence of a limited set of universal basic terms, notably eleven, which refer to colours in the same way in all world languages. The second one affirms that these terms appear in the lexicon following a specific evolutionary sequence: languages do not select randomly the basic terms of this inventory.

The evolutionary order of the basic color words is organized in seven succeeding steps. In the first step, the two coded categories are the focal black and the focal white; if a language has three BCTs (step two), this will be red, including red, yellow, orange, brown, pink and violet shades. The third step is more complex since we can have two possibilities: the appearance of green or the appearance of yellow; the color which has not emerged in the third step, will appear in the fourth one. The fifth step is linked to the emergence of blue from the green region, whereas in the sixth step we find the new category of brown. In the last step, the seventh one, several categories join the lexicon, notably purple, pink, orange and grey.

There exists, thus, an implicational hierarchy and two possible temporal orders:

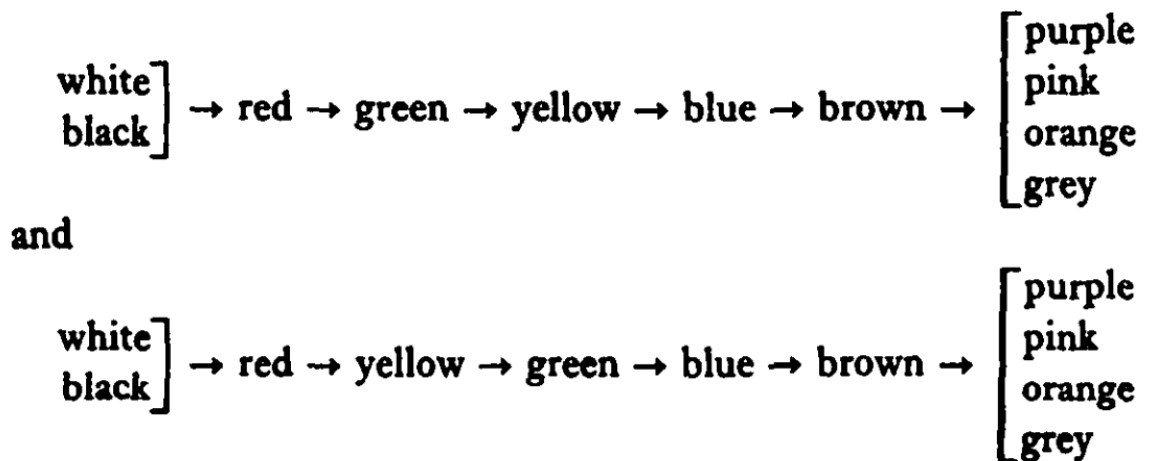


Figure 16: The Basic Color Terms and the evolutionary order (Berlin and Kay 1969: 104)

In figure 16, we can clearly understand how the evolutionary hierarchy must be interpreted: the presence in a language of a color category to the right of a narrow path involves the presence of all the categories to its left. On the contrary, the opposite implication will not necessarily be valid (Taylor 2003)

1.3.3.2. Language segmentation and cognitive processes in color categorisation

As mentioned above, Berlin and Kay (1969) developed the theory of the basic color terms in response to the relativist approach which assumed that the light spectrum segmentation was arbitrary. The authors aimed to prove that the existence of color categories partitioning the light spectrum could not be arbitrary nor random; this presupposition led to the hypothesis of a neurophysiological basis of color categorisation (Jraissati 2009).

However, in their work, Berlin and Kay do not explicitly mention specific neurophysiological notions for their two main assumptions, notably the restricted number of eleven basic color words and their evolutionary coding in language.

The authors' problem is that their study on twenty languages produced very distinct results in the identification of focal points and in the delimitation of categorical boundaries. In fact, if the first data group involving the focal points is relatively uniform, the second one on categorical boundaries varies across speakers of the same language. This important variation does not allow the color categories boundaries to be relevant in the definition of the category itself.

Moreover, the category extension of BLACK at step 1 is different from the category extension of BLACK at step 5: following the presupposition that each language evolves to enrich its lexicon, the respective extensions of lexical categories also evolve over the different steps. There, thus, exists a substantial difference in regularity between data

about focal points and data about categorical boundaries which is not easy to explain from a universalist approach.

We succeed, in fact, to clearly perceptually distinguish a focal point from another, as well as all the colours to which color terms refer to (their extensions), but the individual chromatic boundaries cannot be explained as language controlled.

One of the possible explications the authors evoke is linked to the cognitive processes which are independent to language:

“It is possible that the brain’s primary storage procedure for the physical reference of color categories is concerned with points (or very small volumes) of the color solid rather than extended volumes. Secondary processes, of lower salience and intersubjective homogeneity, would then account for the extensions of reference to points in the color solid not equivalent to (or included in) the focus.” (Berlin and Kay 1969; p.13)

For Berlin and Kay, in fact, color categorisation would depend on primary cognitive processes involved in the stockage of physical stimuli with a reduced size in color space; on the contrary, categorical extensions would rise from secondary cognitive processes with a lower intersubjective uniformity. Consequently, the categorical extensions variable across subjects are not essential in the concept of color definition.

In 1969, Berlin and Kay did not develop a specific theory on the cognitive processes responsible for color categorisation based on focal points, but their considerations about a possible explanation founded on cognition represent the starting point of the other theories developed later.

All these theoretical aspects highlight that the Basic Color Terms’ Theory is a complex theory: from one hand, it is based on the physiological processes at the low-levels treatment of visual stimuli; from the other hand, it is a cross-disciplinary approach

combining studies on perceptual physiology, psychology, linguistics and ethnography. For this reason, the BCTT needs constant deep exploration in distinct fields.

It has evolved in time, developing new hypotheses, especially for the case of languages whose color categorisation cannot follow the initial scheme of the BCTT. New versions have emerged, considering the more recent discoveries in the science of vision: from a point of view radically universalist on color categorisation, the theory has moved to a more moderate point of view.

1.3.3.3 The evolution of the BCTs Theory: from 1969 to nowadays

The first version of the BCTT has been revisited many times since 1969. At the present time, as Jraissati (2009) propose, we can distinguish four BCTs Theories from 1969 to 2005: each of them focuses on the evolutionary sequence, on the color basic categories (focal points and categories' boundaries), as well as the physiological foundations of color discrimination.

In this section, we will briefly present these four steps following the contribution of other researchers to the evolution of Berlin and Kay's theory.

1.3.3.3.1 The first theory: from 1969 to 1972

The first formulation of the BCTT in 1969 was mostly a set of data and observations supported by theoretical implications. However, between 1969 and 1975 some studies in the field of experimental psychology principally conducted by Rosch-Heider on color categorisation allowed the definition of the theoretical basis (Rosch Heider 1972a; 1972b; 1973; 1975; 2002; Rosch et al. 1976; Heider and Olivier 1972; Heinrich 1972; Berlin and Berlin 1975; Dougherty 1977; 1975; Hage and Hawkes 1975; Kuschel and Monberg 1974).

The most important contribution of Rosch-Heider is the notion of “focal color”, that we will present in detail in the next section of this chapter. For the moment, it suffices to mention that she tried to demonstrate the focal colors’ independence from language, as well as their psychological and physiological nature.

She elaborates a developmental hypothesis explaining how the perceptual salience of specific color space regions can lead to the emergence of a universal reference labeled by a basic color term, and then to its conservation (Heider 1971). To verify her hypothesis, she decides to study the lexicon of a population which does not have these color words in order to control the way in which these terms are learnt.

At the same time, Rosch-Heider, in collaboration with Olivier, introduces the notion of “memory” (Rosch Heider 1972) to test the following hypothesis: if language determines perception, the color codes should impact the memory of color images. Since this relativistic hypothesis, already proposed in 1956 by Lenneberg and Brown (Brown and Lenneberg 1954), can be verified by the comparison of two languages with different lexical categorical structures and color space partitioning, Rosch-Heider and Olivier conducted some studies on English and Dani, a Trans-New Guinea language, on color chips memorisation.

Their results showed a clear difference in the color terms’ partitioning of perceptual space in Dani and English, but these distinctions do not reflect the color space partitioning in memory. In fact, the two perceptual spaces, in Dani and in English, have similar characteristics in the way in which they emerge in memory: language does not influence memory nor color recognition.

These findings clarify the question involving the relation between the verbal encoding and the mnemonic precision, too. Knowing whether the precision in the color words encoding impacts the precision of its memorisation is no more sufficient; on the contrary, the main important aspect is the easiness in the memorisation of focal colours compared to non-focal colours.

For the developmental hypothesis proposed by Rosch-Heider (1972), we remember more easily focal colours associated to basic color terms than non-focal colours : the central

notion of memory suggests, thus, in infants color words are not simply associated to salient color regions, as affirmed by Berlin and Kay (1969), but they are associated to focal colours which are better memorized.

The differences between the encoding of the basic color terms and their memorisation is strictly linked to the hypothesis expressed by Rosch-Heider about the evolutionary order: it states that the memorisation of color words would follow the sequence established by Berlin and Kay, or BLACK-WHITE, RED, YELLOW-GREEN, BLUE, BROWN, PINK-GRAY-ORANGE-PURPLE.

Even though the results of his studies did not show this order in the mnemonic precision in all languages, the author continued to affirm that almost the first four color categories of the Berlin and Kay's sequence are those more easily encoded and remembered (RED, YELLOW, GREEN and BLUE). The salience of some color space regions, thus, passes through their physiological rooting, but to understand the universalist behaviour proposed by Berlin and Kay, Rosch-Heider (1973) introduces the notion of "prototype".

She proposes that the color perceptual field is structured in non-arbitrary semantic categories, developing in natural prototypes which are perceptually salient. His notion of prototype replaces the notion of salient focal regions, introducing the new concept of gradation. Natural categories partition, in fact, all the perceptual fields whose stimuli are composed by continuous variations; in this continuum, the categorical boundaries are not well defined and some stimuli are perceived as being better examples of one category than others. This process concerns color perception, too.

For Rosch-Heider, the perceptual salience, which is rooted in the so-called "primary colours" in neurophysiology, thus creates some prototypes, a psychological notion, which represents the salient stimuli primarily associated with basic color terms in different languages. This assumption attests the universality of the focal points, as well the Berlin and Kay's argument (1969) stating that color categories have to be analysed following the focal point and not the category boundaries.

To conclude, the work of Rosch-Heider between 1971 and 1973 on color categories put the basis for the following developments of the BCTs Theory which started in 1975. Through her contributions on the notion of focal colours, prototypes and on their physiological and psychological nature, she confers a gradual structure to color categories, which will be crucial for the subsequent theoretical versions.

1.3.3.3.2 The second theory: from 1975 to 1991

The second BCT theory was developed between 1975 and 1991 and started from Rosch-Heider conceptual assumptions specifying the perceptual determination of color categorisation.

The first factor introduced in this version is the theory of fuzzy color categories' sets which allows the understanding of the variability in boundaries with the reintroduction of the notion of color boundary in color categorisation. In fact, the first fundamental transformation dates from 1978 with the publication of Kay and McDaniel's article (Kay and McDaniel 1978); however, Kay had already found out in 1975 that the first theory of 1969 had some important limits. He, thus, reconsidered some notions and conceptualized the evolutionary dimension in order to make it useful for experimental tests.

In "Synchronic variability and diachronic change in basic color terms" (Kay 1975), Kay reformulates the encoding sequence of the theory's first version basing on additional empirical works on color lexicon (Berlin and Berlin 1975; Heider and Olivier 1972; Dougherty 1975; Hage and Hawkes 1975). Kay and McDaniel (1978) proposed a new model where we find the fuzzy unions of the six primary categories (green or blue, red or yellow, white or red or yellow, black or green or blue) that are named only in the first steps of evolutionary systems. The evolutionary sequence was, thus, modified.

From a conceptual point of view, the most important variation is the distinction between the notion of category and the notion of focal point. In 1969, in fact, since the authors had to deal with a greater variability in categorical boundaries compared to a surprising

regularity of focal points, the notion of color category corresponded to that of focal point, allowing less importance to the boundaries. This aspect has been criticized by Kay and McDaniel in 1978 (1978) even though in 1975 Kay has affirmed that:

« These facts about color foci have an important implication, namely that the operative element in the sequence at stage 3 is neither the focus green nor the focus blue but the category grue.
» (Kay 1975: 260)

The evolutionary sequence is no more based only on focal points, but on the interaction between focal points and categorical boundaries, which play an important role in the constitution of the sequence.

Hence, at the first step of the sequence, the lexicon has two basic terms (WHITE and BLACK), but they also include in their extensions other colours and shades: WHITE, for example, integrates light hues and warm colours which can have their focal points in white, pink and red regions of the color space. In the same way, BLACK can integrate dark hues and cold colours with focal points in black, blue and green regions.

At the second step of the sequence, RED emerges as a basic color term, including in its extension all warm colours: in the new version of the theory, RED is not considered as emerging from WHITE and BLACK, but it only detaches from WHITE. Each color term has different extensions during the evolutionary steps: for instance, the word encoding the black category does not have the same extension at step 1 compared to the step 4 or 5 in the order evolution. Moreover, the labelling referring to a color category (e.g., BLACK) can specify both the focal point and the category extensions which, in turn, is not constant across languages nor inside the same speakers' community. This color categories' boundary variability is caused by the formalism of the 1969 theory since each color can correspond to more than one basic category. At the same time, the absolute limit of a color category is the category beyond which this category is never extended, and it corresponds to the focal points of the adjacent color categories.

The Kay and McDaniel (1978) theory of fuzzy color sets, thus, substitutes the theory of standard sets for the definition of the relation between the focal points and the extensions of color categories. One of the most relevant modifications they introduce is the assumption that basic color categories have a universal focal point and universal absolute boundaries.

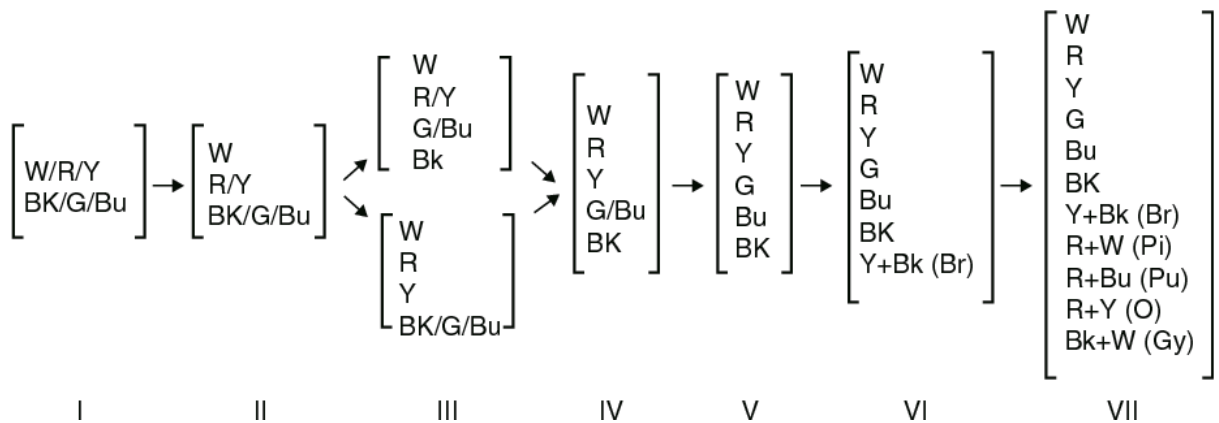


Figure 17: Basic Color Terms and the Evolutionary Order in 1978.

Another important innovation of the second version of the BCTT is the study of synchronic variations inside the diachronic changes. The temporal dimension has, in fact, a central place in the lexical theory based on the evolution of vocabulary.

Kay (1975) did not consider the linguistic community as a uniform group anymore; on the contrary, he considered it as heterogeneous. Therefore, to measure the evolution of a linguistic group, he now took into account the synchronic variations, in addition to the diachronic ones. This new perspective allows a finer analysis of the variations identified inside the same linguistic community and its members, which can be linked to the lexical evolution of the linguistic system. The main statements involving the interconnection of the diachronic and synchronic evolution are the following ones:

1. If all the speakers of a linguistic community are at the color lexical evolutionary step n , then all the secondary more salient color terms will be the basic terms of steps $n+1$, $n+2$, $n+3$, and so on.
2. The relative degree of salience of secondary terms should correspond to the order in the evolutionary sequence (for instance, at step 1, the most salient secondary term should be RED).
3. When a lexical change appears in a linguistic community, all the locutors will not be at the same evolutionary step of the lexicon (each speaker can be classified in a different step).
4. When a lexical change appears in a linguistic community, the whole evolutionary steps of the community itself will be contiguous in the evolutionary sequence.
5. When a lexical change appears in a linguistic community, the basic color terms added to the subsequent steps are represented as secondary words for the speakers being at anterior steps in the evolutionary sequence.
6. When a lexical change appears in a linguistic community, the speaker's step depends on various social factors, especially the speaker's age.

Another fundamental point of the 1978 theory is the neurophysiological basis of color semantic categories. The first version had, in fact, defended the thesis that color semantic categories are universal and that the linguistic universals are inherent to human perception. On the contrary, the 1978 theory highlights the correspondence between focal colours and the neurophysiological nature of perception, based on various studies, like those conducted by Jameson and Hurvich (1955) and De Valois (De Valois and Abramov 1966; De Valois and Jacobs 1968; De Valois, Morgan, and Snodderly 1974). The semantics of color terms is, thus, associated with this neurophysiological theory since it directly reflects the existence of neural response categories.

In 1991, Kay, Berlin and Merrifield published the article "Biocultural implications of systems of color naming" (Kay, Berlin, and Merrifield 1991) which will represent the

turning point between the second and the third version of the BCTT. In their article, the authors focused on the theory of fuzzy sets and on the neurophysiological rooting of color categories identified by neural responses, where they introduce the notion of “Fundamental Neural Responses” (FNR), or the distinct neural response processes to color categories. This concept concurred to explain the correspondence between lexical category and neural response: a basic color term coding a composite category is, thus, a unique term which encodes a spectral region including two or more FNR. For the authors, in fact, the fundamental neural response categories correspond to the six primary color sensations whose neural substrate was constituted by the six types of cells identified by De Valois (De Valois and Abramov 1966).

In conclusion, the development of the BCTT between 1975 and 1991 lies on the basis put by Rosch-Heider between 1969 and 1973. The introduction of the FNR and the colours modeling through fuzzy sets cause a central conceptual change, or the notion of “composite category” allowing, for example, the identification of “mixed” categories, like green-blue (Y/G). The BCTT’s defenders defined this effect as a categorical “puzzle”, notably for the Y/G category, which will represent the focus of the third version of the BCTT.

However, at this point of the theory we can recognise a sort of moderate linguistic relativism, especially for the presence of a linguistic determinism, even though it is quite limited. It, in fact, does not share the assumption that the semantic systems vary across languages without any constraints. The question involving the conceptual implications of a “whorfian” effect will be analysed again, in other different contexts, during the theory of 2000 formulation.

1.3.3.3.3 The third version of the BCT theory: from 1991 to 1999

In more recent years two additional versions of the BCT theory have appeared to refine the original model (Kay, Berlin, and Merrifield 1991; Kay et al. 1997; Kay 1999; Lyons 1981; Lyons 1995) with the addition of two main empirical surveys, supporting the hypothesis of semantic universals and the evolutionary sequence in the development of a basic color lexicon. The two surveys are: the World Color Survey (WCS) and the Mesoamerican Color Survey.

The first assumption made by Berlin and Kay in 1969 that has been challenged, is the proposition that “all languages possess a small set of words (or word senses) each of whose significatum is a color concept and whose significata jointly partition the psychological color space” (Kay 1999: 1), where the significatum corresponds to the chromatic perception the word refers to and the significata correspond to the lexical forms. Several authors (Saunders and van Brakel 1997; 1988; 1995; Levinson 1997; Maffi 1990; Lucy 1966; 1997) have rejected this hypothesis and proposed an alternative theory, the Emergence Hypothesis (EH), for which not all languages possess a small set of words (or words senses) with the characteristics identified by Berlin and Kay (1969).

The third version of the BCTT begins, in fact, with the analysis of a particular problematic category: the Y/G category. The yellow/green category has been detected for the first time after 1969, then studied in 1987 by MacLaury and, several years after, six languages have been identified by the World Color Survey. This version of the theory aims, thus, to explain the nature and the existence of this category, inside the theoretical universalist context: this explanation is possible only if we admit the EH as a working hypothesis. Since for the EH it is not necessary that all languages, at the anterior levels of their lexical development, jointly partition the perceptual space of colours, in some languages certain categories emerge without any previous marks and are easily detectable by the fact that their extensions are reduced.

The Emergence Hypothesis is introduced in the article «The emergence of basic color lexicons hypothesis» by Kay (1999), in response to Lyons’ critics who does not accept the assumption that color terms are fixed and limited in number and that each of this color word “signifies” a specific color concept. Lyons especially questions the principle of the

joint partitioning of the color spectrum made by color terms, which, even implicit to the BCTT, guides the choice of basic terms underlying the lexical systems. For her, in fact, it is not necessarily true that a limited number of words are combined to partition the color space in a specific language; as a result, a color category can emerge without passing through the usual evolutionary sequence advocated by the theory.

Moreover, Lyons introduces in her evolutionary sequence model two additional categories: LIGHT-WARM, including WHITE, RED and YELLOW in its extensions, and DARK-COOL, including BLACK, GREEN and BLUE. The two incorporate the dimension of brightness which plays a predominant role in some languages.

The new model of EH is based on the partition principle, which explains the tendency for languages to lexically partition notionally salient domains, such as the human body or the periods of the solar year, in different ways. This strong partitioning tendency across languages does not exclude the existence of non-partition languages or the transition for one language from non-partition to partition languages. The domain of colours is one of the best examples of this evolution: colours, in fact, bring a great amount of information about an object, allowing its identification and discrimination. This relevance had an impact on the salience of the color domain which led to the development of additional basic color terms, with a refinement of the lexical partition of languages' color domain (Casson 1997).

Neurophysiological critics are another aspect defining the third theory of basic color terms: Kay and Maffi (1999) call into question Hering's notion of pure colours (Hering 1878, 1964), described as colours physiologically based on post-retinal level treatment. This objection excludes the notion of FNR, which had been central to the second version, too.

For the two authors, in fact, the six classes of cells identified by De Valois and his colleagues (De Valois and Abramov 1966) cannot be the neural substrates of the six pure colors' sensations for two reasons: first of all, considering that a pure color stands outside the visible spectrum, it cannot coincide with the neural response of a specific cell type.

Second, the points at which the chromatic opposing cells are not excited or inhibited do not correspond to the points at which the unique colours are observed.

These remarks lead to a conceptual dissociation between the notion of pure colours, physiologically supported, and the notion of pure color sensations. The basic character of these six colours is no longer considered as founded on neural responses.

The third BCTT is, thus, characterized both by a substantial theoretical development, with the presentation of the Emergence Hypothesis and the partition principle, and by the rejection in 1997 of the FNR, or the pure colours described by Hering from a physiological point of view. This rejection stimulates some debates about the modelisation of the partition principle and on the universalism of color categorisation which will be solved in the fourth version of the BCTT. In fact, as we will explain in the next section, the BCTT's defenders will accept, during the 2000s, a more relativistic version of the theory, based on the assumption that language has a non-trivial influence on perception which, in turn, determines color categorisation.

1.3.3.3.4 The fourth version of the BCT theory: from 1999 to 2006

Between 1999 and 2006, the debate opposing universalists and relativists about the relationship between the color lexicon and perception retook place in the BCTT, after the publication in 1999 of an article dedicated to the study of Berinmo, a language of Papua New Guinea (Davidoff, Davies, and Roberson 1999). Davidoff and his colleagues especially criticize the conceptual contributions of Rosch, mainly based on Dani experimental data, which have been interpreted as a proof of the universalism of color memory and categorisation for a long time.

In 2000, Roberson conducted some studies with his team (Roberson, Davies, and Davidoff 2000) in order to demonstrate that color memory and color verbal coding are not independent, and that focal colours are not necessarily more easily learnt in association

to basic terms than other colours. They questioned the psychological nature of focal colours, affirming that color categories and their extensions are linguistically determined. Their results contrasted with the previous findings of Rosch in Dani and furnished an argument in favour of the linguistic relativistic thesis.

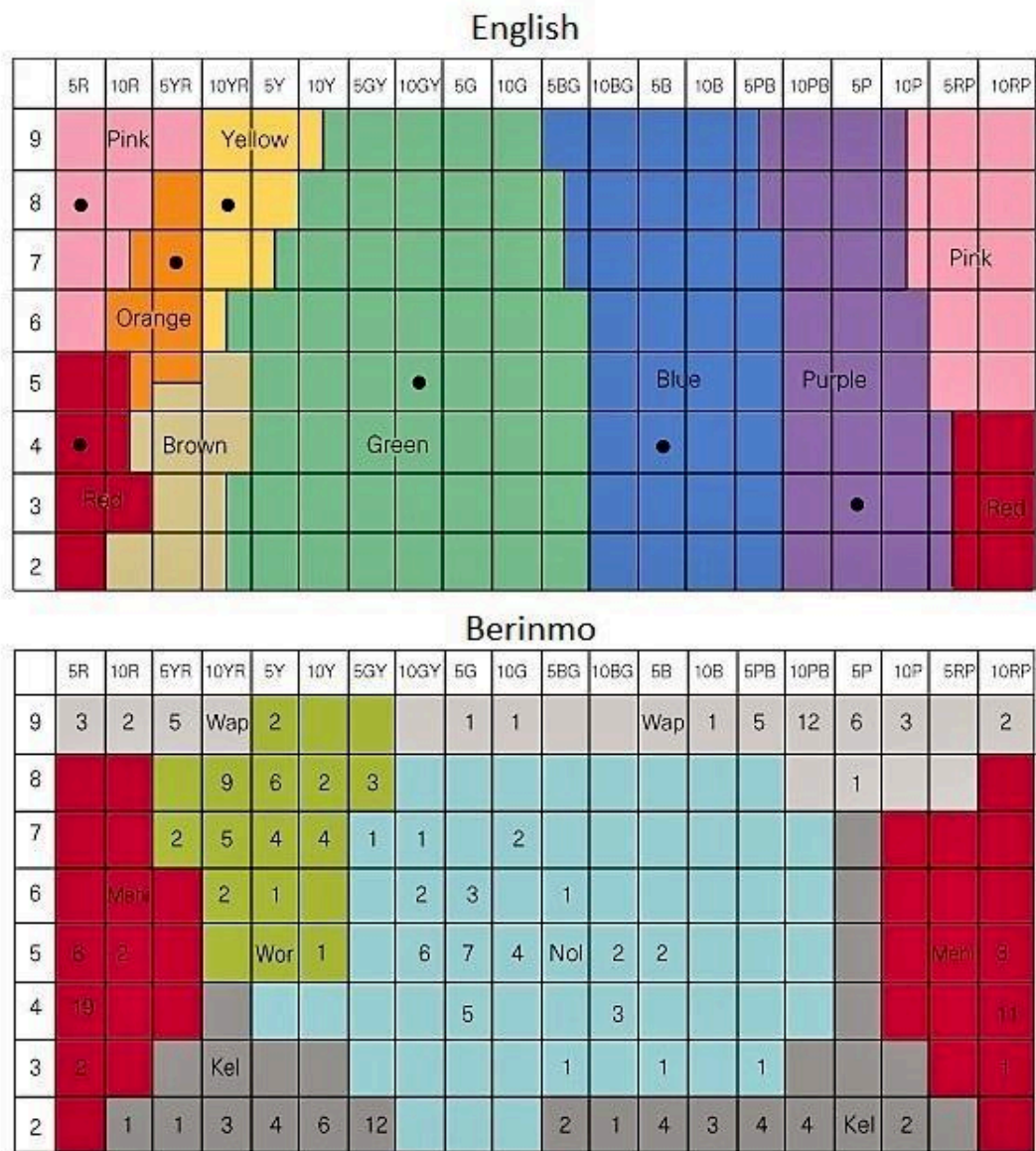


Figure 18: Color categories in Berinmo and English (Roberson, Davies, and Davidoff 2000).

Berimo color categorical boundaries are compared to English ones: the differences between the two (Figure 18) are linked to the effects of categorical perception across boundaries, already mentioned by Kay and Kempton in 1984 (Kay and Kempton 1984). Roberson's results show that the categorical perception emerges only for the speakers of a language which lacks the lexical distinction. Inversely, following Rosch and Olivier's results (Heider and Olivier 1972), the speakers of Dani were able, independently on the color lexicon, to categorize colours as English speakers since their color spaces were similar.

For their part, between 1999 and 2005 the BCTT defenders tried to counter this argument through statistical analysis showing that focal points have a psychological nature: even though the effects of categorical perception on the lexical categorical boundaries seem to depend on lexicon and not to be innate, they continue to affirm that color categories are organized around the focal color.

At the same time, Robertson and his colleagues (Roberson, Davies, and Davidoff 2000) further analysed the link between cognitive categories and linguistic categories (Roberson et al. 2006). They stated that the visual system limits perception, but it does not necessarily participate in color categorisation, which is a high-level cerebral process. Color categorisation is, thus, represented as a physical continuum qualitatively discontinuous and differences can be caused by lexical categories learning. If infants had a set of universals since birth and the structure of the visual system was determined by color categorisation, then the color lexicon would be easy to learn.

However, color lexicon has never been tested from a statistical point of view; the universalist and evolutionary hypotheses (UE theory) (Kay and Regier 2006; Kay 2002) affirmed that there exists some universal constraints in color lexicons, based on the eleven basic color terms identified in 1969 and on the Hering's six primaries. Kay and his colleagues, thus, decided to statistically demonstrate that categories and their extensions are not arbitrary, introducing the notion of "geometric center" (Kay 2002). The geometric center of a color term is the center of the category extension, computed from its boundaries.

Their research attested a sort of agglomeration of geometric centers across languages; since the geometric center is the mean value of different categories, these categories have comparable extensions across languages. Therefore, there exists an inter-language regularity in the color space partitioning.

On the other hand, the debate continues with Roberson and his colleagues who defended the idea that color categories are defined by their boundaries which are linguistically determined: color categories are arbitrary and are not organized around focal points. To contrast this position, in 2005 Kay and Cook (Regier, Kay, and Cook 2005) analysed the WCS data concerning 110 languages whose focal points have been identified. In particular, as attended, the focal points with the highest degree of consensus were those of WHITE, BLACK and RED categories: these findings represented a proof of the perceptual salience of focal points.

Kay and colleagues also engaged in an additional analysis with the aim to demonstrate the universality of focal points, as well as their psychological nature. Through the notion of geometric center and a probability calculation, they attested that color categories were not randomized because the geometric centers directly depended on the categorical extension, thus on the boundary position (Kay 2002; Kay and Regier 2003). The authors can, anew, confirm the universal salience of focal points (Regier, Kay, and Cook 2005): the comparison between the degree of agglomeration of geometric centers and the degree of agglomeration of focal points has, fact, shown that the focal points tend to agglomerate more closely than geometric centers. This effect means that they play a central role in the determination of color categories compared to boundaries; at the same time, color categories are constituted by focal points representing the regions of the color space more easily detected.

The question of the boundaries' variability is discussed by Kay, Regier and Cook (Regier, Kay, and Cook 2005), too. In "Universal foci and varying boundaries in linguistic color categories" (Regier, Kay, and Cook 2005; Kay and Regier 2003) they affirm that categories boundaries are predictable from their focal points, almost universal, through the elaboration of a computational model whose central concept is that different languages have color terms organized around different subsets of the six universal focal points (the

Hering's primaries). Thus, some languages have only three categories corresponding to the English words "black", "white" and "red", while others have also some categories around the English terms "blue", "green", "yellow", and so on. In this model, the language focal points assign the prediction of category boundaries, which vary in function both the number of the language basic terms and of the focal points.

The main characteristics of the fourth version of the BCTT is the acceptance by its defenders that language has a relevant influence on perception: Kay and Regier (Kay and Regier 2006) recognise that there exists a great number of proofs attesting the impact of the language treatment on cognition. However, this observation is unsatisfactory to support a linguistic relativistic theoretical position. In fact, Roberson, David and Davidoff have finally concluded that color categories are determined by boundaries, not by the focal points, and that there does not exist universal constraints on boundaries for color terms.

The Basic Color Terms' Theory, thus, passes from a radically universal viewpoint, for which categories are universal and language has any influence on cognitive non-linguistic behaviors, to a more mixed, moderate position. In this new approach, color categories are universal, organized around focal points, but language has an impact on cognitive non-linguistic treatment to a certain extent. The adoption of this new mixed position is the peak of the BCTT's evolution which had started in 1969 to contrast the relativist hypothesis that language can have any kind of influence on perception.

Therefore, this new approach especially highlights the need to overtake a stricter conceptual framework, which has limited for decencies the dichotomic debate on the relation between lexicon and perception in the color domain.

If, despite the universality and the psychological nature of the focal points, we may affirm that language has a non-trivial influence on the categorical boundaries' perception, then

the theoretical dichotomy between universalism and relativism in the domain of color perception can be considered overcome. The BCTT defenders stress themselves the need to eliminate this stronger theoretical context, starting in 2006 a new series of experiences on the influence of language on categorical perception. In fact, accepting the hypothesis that categorical perception depends on language, their objective is to try to define the psychological and/or physiological processes subordinate to this relation.

1.3.3.4 Global Critics to the BCTs Theory

As we showed in the previous sections, the first version of the theory of Basic Color Terms in 1969 represented a real revolution in the field of color categorisation and perception in different domains: anthropologists, psychologists and linguists mostly embraced its findings (Bornstein 1973, 1975; Brown 1976; Collier et al. 1976; Miller and Johnson-Laird 1976; Ratliff 1976; Shepard 1992; Zollinger 1988b, 1988a, 1979, 1984). However, others expressed doubts and scepticism, especially for its methodology and substance (McNeill 1972; Collier 1973; Conklin 1973; Durbin 1972; Hickerson 1971; Caskey-Sirmons and Hickerson 1977; Sampson 1980).

Some of these critics have contributed to the BCTT evolution, through the definition of different versions, in order to make it more solid on its universal ambitions and more accurate in the methodology chosen, as well as for its formulation and modulation. However, the most global relevant ones are reported in the following paragraphs.

The first remarked critics to the BCTT are those made by the anthropologist Nancy Hickerson (1971) who attacks Berlin and Kay on four main points, notably the vague number of speakers interviewed for each language (sometimes only one or two, without any information about the cultural context); the arbitrary definition of the basic color terms; the ambiguity of the linguistic labellings of the evolutionary sequence, obtained through conventions which are not explicit; and finally, the exclusion of the categorical

boundaries without any explication. The variability of categorical boundaries is, in fact, not taken into consideration and the question involving the universal categorisation is only based on the focal points.

Hickerson's criticisms will be reiterated by other authors for almost twenty years (Lucy and Schweder 1979; Crawford 1982; Saunders and van Brakel 1997; Roberson, Davies, and Davidoff 2000; Roberson et al. 2005).

Kay (Kay 1975) and Kay and McDaniel (Kay and McDaniel 1978) directly and indirectly recognised some of Hickerson's critics, notably the two last points, since they admit that labelling was employed in a vague manner referring sometimes to the focal point and sometimes to the category's extensions. Therefore, with the notion of absolute limit, they resolve the question of the color boundaries and their variability, especially for basic terms like GREEN-BLUE.

Other theoretical, methodological and linguistic critics came from Lucy (Lucy 1966, Lucy 1997) and Saunders and van Brakel (Saunders and Van Brakel 1988, 1997) which mainly reflected on the notion of "linguistic universals" and on the definition of "basic color term" which are not clear for them.

Lucy (Lucy and Schweder 1979; Lucy 1997) for example examines the parameters on which basic color terms are chosen, especially for languages whose syntactic rules are still unknown. For him, in fact, the application of the criteria for the identification of the basic color terms is arbitrary: the experimenter chooses the universal color category to which the identified category corresponds in a specific language and, thus, the methodology ensures the expected results.

Moreover, he alerts on the confusion between linguistic categories and cognitive categories, calling into question the dialogue between different fields of study on the domain of color lexicon. It is necessary to analyse all the psychological and neurophysiological theories before choosing the best model able to explain the correspondence between the psychophysical and the neurophysiological channels.

The last point criticized by Lucy, Saunders and van Brakes concerns the stimuli used by Berlin and Kay in their experimental tests. For them, in fact, the coloured chips used to

solicit color words do not furnish an adequate knowledge of the lexical system: the chromatic dimension is, in fact, considered by the defenders of the BCTT as the prior defining factor compared to the saturation and the brightness dimensions.

The two last critics we mention in this thesis mainly concern the correspondence between pure colours and maximal neural responses, and the linguistic lexical theory of the basic color terms.

The first one is moved by Jameson and D'Andrade (1997), who have been the first to highlight that the chromatic axis, one of the central factors of the chromatic processes of opposition, are not Red/Green and Yellow/Blue. For them, the model of chromatic opposition consists of two output systems, described by two curves; the intersection point of each curve with the x-axis defines a pure color. For instance, at 580 nm the chromatic response of the R/G curve is null, whereas the Y/G curve reaches its peak: therefore, we observe a pure yellow color; however, at this longwave we do not really see a yellow color, rather than a red-orange hue. This effect questions the correspondence between pure colours and the neural maxima responses, corroborating the proposal that the subjective purity of colours to specific longwaves is determined by cells in the lateral geniculate nucleus (LGN). Since it cannot account for the totality of the color perception phenomenon, this model has, thus, been substituted by a more complex one where the primary colours arise at the cortical level. In this case, Hering's primary colours would play an important role in the cognitive processes of color perception because, independently of their perceptual retinal status, they remain the major junction between color vision and color semantics.

The second critic is supported by Lyons (1999) who rejects some of the main criteria of the BCTT's definition of basic color term. He especially condemns two general linguistic principles subjacent the criteria of the basic color terms' definition, notably the etymological fallacy and the myth of literal significance: "The traditional, simplistic, notion that each word in a language has a fixed number of one or more separate (but related) literal meanings, each of which has fixed and sharply drawn, rather than somewhat fuzzy, boundaries." (Lyons 1999; p.58)

The two assumptions, which are strictly linked and are at the basis of the contemporary linguistic theoretical framework, would suppose that in each language, the words have a limited and fixed number of literary significations which are distinctly determined; among these literary significations, only one is considered “true” as basic, primary and original. At the same time, Lyons condemns the importance given to the etymology of a lexeme in its synchronic meaning since investigating the origin of a word does not provide the actual meaning of this word. Etymology is, thus, irrelevant when we do not study the diachronic meaning of a lexeme.

To conclude, as we mention at the beginning of this section, Berlin and Kay and their theory on color categorisation has been exposed to several critics on different points from various scientific domains. However, these critics have allowed the evolution of the theory, as well as its refinement until nowadays.

1.3.4 Linguistic categories of chromatic perception

The association between color categorical perception and the lexical studies is developed on two main debated positions, mainly contrasting on the nature of color categories, innate or learnt, and whose central point is the notion of categorical perception, introduced by Harnad in 1987 (Harnad 1987). In this context, categorisation is analysed through the observation of the discrimination and identification of color categories: in the first case, the main interest concerns the degree of subtlety to which we can discriminate physical differences; whereas, in the second case, the focus is put on the stimulus types named in a coherent way. Categorical perception is, thus, defined as the speaker’s ability to better discriminate physical differences between two adjacent stimuli which state on both sides of the lexical boundaries, than two adjacent stimuli which belong to the same side of the lexical boundary (for example, in the color domain the word “green” refers to

all the color hues perceived as green delimiting the boundary of the green category which is separated from another category, for example the yellow category, which is linguistically bordered by the word “yellow”). In other words, the same perceptual distance occurring between different adjacent colours is perceived more or less significant depending on the presence or not of a lexical boundary between two stimuli.

The questions arise from this effect have been investigated for several years, but results have often been contradictory: as mentioned above, data on categorical perception in preverbal infants and animals are usually considered as an argument in favour of the innate nature of categories; on the other hand, a stronger discrimination through the lexical boundaries in adults, as well as differences tied to language, are arguments supporting the categories’ language-learning.

However, it is fundamental to remember that categorisation has a functional role: it contributes to the cognitive economy by cutting the environmental variations in units which, in turn, can be manipulated in a more efficacious way compared to continuous variations.

Color categorisation has been studied not only through experimental methods involving lexical categories and color perception, but also through other types of tasks which have shown that, to explain color categorisation and cognition, the irregularity of the perceptual space and the innate skills are not sufficient; in fact, learnt lexicon and contextual factors must be considered, too.

1.3.4.1 Language, Color Space and Categorical Perceptual Effects

Research studies have not already unanimously defined the way in which color categories are related to language and perception. In fact, automatic language processing, bottom-up mechanisms in color perception, as well as categorisation effects in absence of language and perceptual and cognitive aspects in interaction, like attention and memory, indicate that color categorisation can emerge in several distinct situations.

Cross-language studies have especially examined the color space heterogeneity in order to find an explanation for the CP location and its language-variation: speakers of different languages show Categorical Perception only when their language marks the distinction, as Harnad attested (Harnad 1987). As he defined the perceptual color space as *warped* around category boundaries, this warping effect can vary across languages and/or in time and be induced by language learning.

A study of Özgen and Davies's (Özgen and Davies 2002) notably attested that only a few hours of linguistic training to new color categories (e.g. YELLOWY-GREEN versus BLUEY-GREEN) are sufficient to direct CP toward the new learned color boundary. They used the same color study before and after training, but the responses were different: discrimination had, in fact, changed depending on the new categories' location. Language learning may, thus, also modulate pre-existing categories in a language perceptual color space where the categories' strength co-varies with the linguistic categorisation.

Research investigating color space and color CP generally use two kinds of tasks: same-different tasks, like Bornstein and Korda (1984), and successive two-alternative forced choice, like Pilling et al. (2003) and Roberson et al. (2000, 2005). In the two cases, stimuli are perceptually uniform and have equal perceptual distance between adjacent stimuli.

The most used experimental protocol for the same-different task involves a target color followed by a test color after an interval (ISI - Inter Stimulus Interval), which can be either physically different or physically identical to the target color. Subjects have to decide whether the two colours are the same or not. The focus of the experiment is the responses' comparison between stimuli which differ both physically and categorically (for example, BLUE1 - GREEN1) and stimuli belonging to the same category which differ only physically (for example, BLUE1 - BLUE2).

The two-alternative forced choice tasks, in contrast, involve a target color followed by two test stimuli, presented simultaneously after an ISI, which are one physically identical to the target and one physically different to the target. The latter can be either physically

and categorically different or just physically different: subjects must select the one that has the same color as the target.

The two types of studies have demonstrated that participants have better performances when the different test color is categorically and perceptually different to the target than when it is just physically different: this effect has been associated with the color CP. For this reason, color studies have questioned the CP perceptual basis since perceptual processes are not isolated in these tasks: memory is especially engaged in the target color retaining (Pilling et al. 2003). Pilling and his colleagues have also shown the impact of the linguistic labelling in subjects' choice: within-category decisions are, in fact, made by visual perceptual stimuli encoding comparison, whereas cross-category decisions are based on the combination of the visual perceptual stimuli encoding comparison and the linguistic labelling.

Labelling has, thus, been included in the set of factors that can differentially participate in cross-category decisions: when the target and the test stimuli belong to distinct categories, they are also linguistically differently named. This mechanism is almost automatic and generates a more accurate and rapid response. On the other hand, when they belong to the same color category, there is not any salient linguistic label available, so the discrimination is only realised on visual codes distinctions. Roberson and Davidoff (2000) have supported the hypothesis of a language-direct impact on perception showing that if we add a verbal interference during the task, the CP disappears; however, CP remains if the interference is visual. Their conclusion is that the verbal task obstructs the labelling retention.

1.3.4.2 Whorfian effects in the brain: the lateralized categorical perception of colours

The assumption that our native language semantic categories influence our view and perception of the world is mainly supported by Benjamin Whorf (1956). This effect has been debated for several years and consensus still oscillates between supporters of the Whorfian hypothesis and its criticism (Casasanto and Gordon 2005; Gordon 2004). Most of the research dedicated to this issue has been centered on the perceptual discrimination of colours in individuals speaking different languages. As mentioned above, the majority of the findings demonstrated that colours crossing a lexical boundary are perceived as more different by speakers marking the lexical distinction as compared to speakers whose native language lacks this lexical distinction at a specific position in the color space, like in Kay and Kempton (1984). However, even though some researchers have recorded some effects of language on cognitive and perceptual aspects (Kay and Kempton 1984; Roberson and Davidoff 2000; Witthoft et al. 2003), others have failed (Franklin et al. 2005; Rosch Heider 1972a; Heider and Olivier 1972).

Recent works have also attested that the whorfian effect of language on color discrimination is stronger in the right visual field than in the left visual field (Gilbert et al. 2007; Roberson, Pak, and Hanley 2008; Franklin et al. 2008; Liu et al. 2009; Fonteneau and Davidoff 2007). However, this phenomenon is not restricted to the domain of colours, but it involves perception in general, as, for example, the discrimination of animal figures (Gilbert et al. 2007), with the supplementary evidence that the magnitude of the asymmetry in the visual field reduced when a secondary verbal task was added. Since this reduction did not emerge when a non-verbal secondary task was added, notably involving the spatial working memory, the lateralized Whorf effect has been considered as having a general impact, reflecting the interaction between perceptual codes and linguistic treatment primarily in the left hemisphere.

The cerebral hemispheric specialization, as well as the passage of projections from one visual field to the other, induces the Whorf effect to be more evident for stimuli presented in the right visual field (RVF) rather than for stimuli on the left visual field (LVF). In fact, for right-handed individuals all the linguistic functions are more strongly associated and

more rapidly treated in the left hemisphere (LH) compared to the right hemisphere (RH) (Wada, Clarke, and Hamm 1975; Davidoff 1977; Armstrong et al. 2006; Simon et al. 1985). These assumptions are supported by the observations that the left hemisphere of the human brain is the language-dominant one, and that the two visual fields project to the brain in a contralateral way.

Some studies have tested this effect of lateralisation, using various perceptual tasks: Gilbert and his colleagues (Gilbert et al. 2005) have, for example, used a lateralized visual search task where participants performed a speeded visual discrimination task. They presented a ring of coloured squares where one of them, the target, had a different hue compared to the others; subjects had to indicate whether the target appeared in the left or in the right visual field. Performances were better in the right visual field, thus connected to the LH, only when the target belonged to a different lexical category than the other squares. On the contrary, any effect or variation had been detected for targets in the RVF or for targets in the LVF belonging to the same lexical category.

Other studies examining the whorfian effect of lateralization have used distinct experimental protocol, like color discrimination tasks (Drivonikou et al. 2007; Daoutis, Pilling, and Davies 2006) and visual search experiments in which subjects were asked to identify a target color stimulus against a uniform background. However, it is important to mention the fact that Drivonikou and his colleagues (2007) attested a weak color CP effect even in the LVF: in this case, the longer RTs have been interpreted as the time needed for the cross-callosal transfer and, sometimes, for scanning (Roberson, Pak, and Hanley 2008; Franklin et al. 2008; Regier and Kay 2009). Similar results have been confirmed by the research conducted by Roberson, Pak and Hanley (2008) who tested English and Korean speakers in a visual search task. Their findings corroborated the assumption that the emergence of a categorical effect for targets presented in the LVF are the evidence of an innate universal categorisation. In fact, strong categorical effects have mainly been detected in the LVF for a color boundary between Korean color categories which does not exist in English. At the same time, CP was found for targets shown in the RVF too, especially for fastest responses, based on the operation of a non-linguistic perceptual processing system which is not affected by category labels since it is in the RH. On the

other hand, the slowest responders showed CP also for targets presented in the LVF because of the transfer of information between the two hemispheres.

Hence, it is assumed that linguistic categories influence perceptual discrimination, preferentially in the RVF and varying cross-linguistically with the color boundaries of different languages. However, since relevant commonalities in the localisation of color-terms boundaries have been detected, some researchers have assumed that the lateralized color CP can be a complete result of learned color categories (Zhou et al. 2010).

Zou and his colleagues have tested this hypothesis using a visual search task where a control group was compared to an experimental group whose participants have received a training period to a new color category. They especially focused on colours that were within-category before training and became between-category after training in order to determine whether these colours would be discriminated faster after the assignment of a distinct linguistic category. They also analysed whether this difference in the RTs was greater for target stimuli presented in the right visual field compared to those in the left visual field because of a lateralized whorfian effect on the new linguistic categories learned.

The results of this study showed that the lateralized color CP can reflect the effect of new artificially learned categories that can violate both the categorisation pattern of the subjects' native language and the universal categorical tendencies in color naming.

To sum up, a lateralized Whorf effect is detected since linguistic categories filter some of the perceived stimuli (Kay and Regier 2006; Regier, Kay, and Khetarpal 2009), but this color CP lateralisation varies with the position of a language categorical boundaries (Drivonikou et al. 2007; Roberson, Pak, and Hanley 2008; Gilbert et al. 2005; Winawer et al. 2007) and disappears when a second verbal interference task is added to the main experimental perceptual task (Gilbert et al. 2005; Winawer et al. 2007). Meanwhile, various studies have attested that linguistic color boundaries tend to be similar across languages since color naming reflects both universal tendencies and local linguistic conventions (Franklin et al. 2008, 2008; Franklin and Davies 2004; Berlin and Kay 1969; Kay and Regier 2003; Webster and Kay 2007; Shepard 1992; Yendrikhovskij 2001).

Moreover, training to new color categories can modulate color perceptual discrimination, producing CP effects (Goldstone 1994; Notman, Sowden, and Özgen 2005; Özgen 2004).

All these findings, from the earliest to the more recent ones, reopen the ancient debate on the relation between language, thought and cognition in color perception, proposing a new possible halfway solution between the universalist and the relativist view.

1.3.4.3 Color naming and categorisation in the brain

In the debate on color naming and categorisation a central question concerns the nature of these cognitive processes, as well as their neural substrates. Various studies have been conducted to identify the neural networks representing color categories in the brain, even though we still lack global consensus (Siuda-Krzywicka et al. 2019, 2019; Bird et al. 2014; Conway et al. 2010).

Functional MRI studies have, in fact, detected some brain areas encoding color categories, notably regions of the frontal lobes, regions of the visual cortex, prefrontal regions and the left posterior temporo-parietal regions (Brown, Lindsey, and Guckes 2011; Siok et al. 2009; Tan et al. 2008; Ikeda and Osaka 2007). Moreover, for some brain networks, there has been observed a category effect: subjects had greater activation for colours belonging to different categories as compared to color stimuli of the same category (Witzel and Gegenfurtner 2011).

Color naming and color categorisation have also been studied in a contrastive approach for the determination of the respective brain regions' activation: Siuda-Krzywicka and her colleagues (Siuda-Krzywicka et al. 2019) have, for example, discovered that color naming and color categorisation are not modulated by the same neural mechanisms. Using functional imaging methods, they observed that the two processes were determined by different neural connections: color naming performance was correlated to left posterior regions, the left medial temporal gyrus and the left angular gyrus, whereas color

categorisation performance mainly involved bilateral posterior regions, the left frontal regions, the bilateral parietal areas and the right temporal ones.

These findings, supported by other studies on pathological cases of brain lesions (Siuda-Krzywicka et al. 2019), provided new perspectives for future research in the unsolved controversy on the mutual role of language and perception in color categorisation.

Without going into details of the fMRI research on color vision, we can conclude that, despite a lack of agreement about the brain loci of color categorisation and color naming (Siuda-Krzywicka et al. 2019), as well as on their possible overlapping, adult color categories have a bilateral distribution in the brain (Brouwer and Heeger 2013; Bird et al. 2014; Persichetti et al. 2015), involving a complex neural network (Siok et al. 2009; Kwok et al. 2011). As a consequence, they are not lateralized to the left hemisphere, depending on language processing, as suggested by Regier and Kay (2009), but occipital, frontal and temporal areas of the two hemispheres are involved in the visual color treatment.

1.3.5 From one language to another

1.3.5.1 Cross-linguistic variability in color categorisation

Languages label ideas into words in different ways: despite the fact that each of them uses separate terms and discriminate different aspects of the same idea, there exists some universal tendencies in word meanings. To explain the functioning of this simultaneous variation in the lexicon and semantic universals, various hypotheses have been proposed. One of them assumes that word meanings are the effects of adaptation to make communication efficient: cross-linguistic variations in semantic categorisation would, thus, be determined by the different languages' solution, while semantic commonalities would reflect the same strategies to achieve the same efficiency (Cancho and Solé 2003; Levy and Jaeger 2006; Mahowald et al. 2013; Piantadosi, Tily, and Gibson 2011).

Recent works have explored the domain of color naming following this approach, developing the notion of “informativeness” of word meaning which could explain various aspects of color naming variations across languages (Jameson and D’Andrade 1997; Regier, Kay, and Khetarpal 2007; Regier, Kay, and Kemp 2015; Gibson et al. 2017). The pressure for efficiency in the information’s communication can, in fact, drive the color naming system to a specific categorical color space partitioning. However, these categories appear in a language lexicon in such a graded evolutionary way that some regions of color space, which were previously not named, acquire categorical terms introducing new color boundaries. In return, this phenomenon could trigger inefficient communication (Lindsey et al. 2016).

Zaslasky and his colleagues (Zaslavsky et al. 2018) reformulate this question analysing, for a definite number of color categories, the categories which maximize the intra-category similarity and those which minimize the inter-category similarity, using the Shannon’s communication model, in figure 19 (Shannon and Weaver 1949).

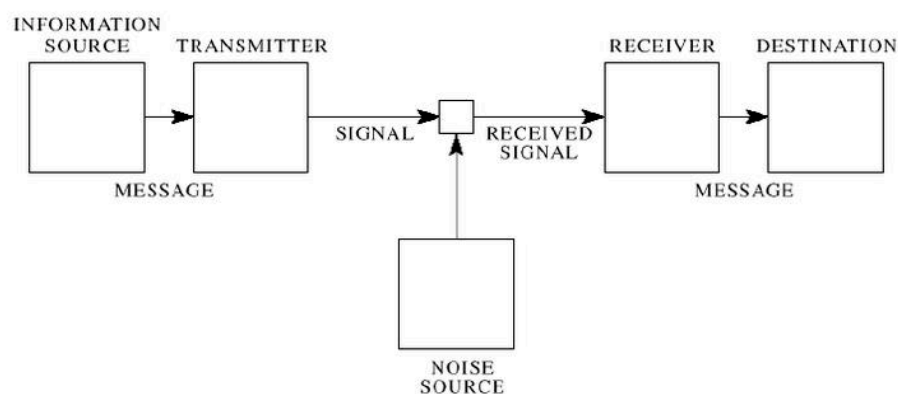


Figure 19: The Shannon’s communication model of 1949 (Kopp 2003). In this model, whose main purpose is to develop the effective communication between a sender and a receiver, various concepts interact to reach informativeness: information source, encoder, transmitter, noise, channel, message, decoder.

In this model, language establishes a communication channel between the speaker and the listener, or receiver, and each language simultaneously optimizes precision in

communication and complexity in the linguistic system. Through the complexity modulation, we finally find the categories universally attested in many languages since each of them searches for optimality in communicative precision and efficiency.

The authors' results, in fact, showed that cross-language variation in color naming can finally be explained as an effect of efficiency: their lexicons evolve following a trajectory to achieve accurate solutions in communication, with the emergence of new color categories in complex systems. Therefore, behind cross-language diversities there exists universal strategies.

Thus, the information theory, which considers informativeness as being central for efficiency in communication in color naming (Lindsey et al. 2016; Regier, Kay, and Kemp 2015; Jameson and D'Andrade 1997; Lantz and Stefflre 1964; Baddeley and Attewell 2009), has become the theoretical framework of several studies, for example that of Gibson, Futrella, Jara-Ettinger, Mahowald, Bergen, Ratnasingam, Gibson, Piantadosi and Conway (Gibson et al. 2017). Their research focused on two main color categories (WARM and COOL) which are considered as fundamental categories even though they are not part of the canonical basic categories proposed by Berlin and Kay (Lindsey and Brown 2006; Holmes and Regier 2017). Using a free-choice paradigm in a color naming task, they tested three groups of different cultures: English speakers, Bolivian-Spanish speakers and Tsimane' speakers, an indigenous community in Amazonia.

The results of the additional analysis of the World Color Survey (WCS) color naming experiments on 110 languages (Lucy 1997; Saunders and van Brakel 1997; Gibson et al. 2017), demonstrated that, despite some cross-language differences, warm colours, like reds and yellows, are always universally better communicated as compared to cool colours, like greens and blues. Cross-linguistic similarities in color naming efficiency, thus, reflects the universal usefulness of some color categories shaped by cultural factors.

The debate on the origins of color categories finds a possible reconciliation through the hypothesis on the efficiency of communication across languages (Piantadosi, Tily, and Gibson 2011; Regier, Kay, and Kemp 2015). In this perspective, culture plays an important role in shaping color categories in common patterns which display the existence of universals in color naming (Gibson et al. 2017; Lindsey et al. 2016). At the same time,

linguistic variations in color category boundaries are linked to variability in communicative efficiency.

1.3.5.2 Focal colours across languages

In their Basic Color Terms Theory, Berlin and Kay (1969) present the notion of focal colours as the best examples of color terms, which are perceptually and cognitively more salient than non-focal colours.

The stability of focal colours across languages has traditionally been considered as both the subjacent origin of universals in color naming (Kay and McDaniel 1978) and the cross-language variation in category boundaries (Roberson, Davies, and Davidoff 2000); empirical data supporting the two approaches exist. In the first view (Berlin and Kay 1969; Regier, Kay, and Cook 2005), languages develop their color-naming systems by grouping the universal foci in categories around the Hering six primaries (Hering 1964), whereas, following the second theory, color categories are determined in their boundaries by language-specific conventions (Roberson, Davies, and Davidoff 2000). For Roberson and colleagues, in fact, the best color examples do not display universal basis for cognitive and perceptual treatment, they are rather an effect of language categorisation: “Once a category has been delineated at the boundaries, exposure to exemplars may lead to the abstraction of a central tendency so that observers behave as if their categories have prototypes” (Roberson, Davies, and Davidoff 2000: 395).

Some proposals trying to conciliate these two opposing stances have been elaborated, like that enounced by Jameson and D’Andrade (Jameson and D’Andrade 1997) who suggested that color naming universals exist and derive from irregularities in the perceptual partitioning of color space, which, in turn, is shaped into categories by linguistic constraints for optimal informativeness.

Informative communication about color is at the heart of another relevant position synthesizing aspects of the two traditional accounts, proposed by Abbott, Griffiths and Regier's work (Abbott et al. 2015). The authors argued that focal colours do not vary arbitrarily since they arise from informative color categories shaped by all languages under the pressure of the same functional forces (Regier, Kay, and Khetarpal 2007; Jameson and D'Andrade 1997). Thus, unrelated languages can have similar color naming systems, based on informativeness, where categories' focal colours are similar, but, at the same time, these color categories can cross-linguistically vary since they represent a different informative partitioning of color space.

Abbott, Griffiths and Regier analysed the best examples of 112 languages with different statistical models, demonstrating that they can be predicted from category extensions: their findings explain both cross-language variations in focal colours and universal tendencies in color categories as the effect of informative communication needs.

The studies we have presented in this section confirm the non-arbitrary character of color categories revealing the existence of a cross-language universality in the individual diversity. However, an important issue rests unsolved: does perception vary with language?

A great number of studies using various kinds of experimental tasks, have attested that the speakers' behaviour varies with the language system; it has been shown, for example, that if two colours share the same color word in a definite language, speakers of this language tend to judge them more similar and to confuse them in short-term memory tasks, as compared to colours labelled with two different terms (Winawer et al. 2007). These differences emerge early in childhood, notably during the infant color lexicon learning, and disappear when a verbal interference occurs.

However, critics to these experimental protocols do not lack: in *The Language Instinct*, Pinker has, notably, attacked the subjective and mnemonic nature of these tasks. For him, most of the experiences only test a banal version of the whorfian hypothesis:

“Some of these experiments have actually worked, but that is hardly surprising. In a typical experiment, subjects have to commit paint chips to memory and are tested with a multiple-choice procedure. In some of these studies, the subjects show slightly better memory for colours that have readily available names in their language. But even colours without names are remembered fairly well, so the experiment does not show that the colours are remembered by verbal labels alone. All it shows is that subjects remembered the chips in two forms, a nonverbal visual image and a verbal label, presumably because two kinds of memory, each one fallible, are better than one. In another type of experiment subjects have to say which two out of three color chips go together; they often put the ones together that have the same name in their language. Again, no surprise. I can imagine the subjects thinking to themselves, “Now how on earth does this guy expect me to pick two chips to put together? He didn’t give me any hints, and they’re all pretty similar. Well, I’d probably call those two ‘green’ and that one ‘blue’, and that seems as good a reason to put them together as any.” (Pinker 1995: 65).

In accordance with the findings of Winawer and colleagues (Winawer et al. 2007) as well as with those of other color specialists’ experiments (Gilbert et al. 2005; Roberson, Pak, and Hanley 2008; Siok et al. 2009; Thierry et al. 2009; Maier and Rasha 2018), the next section of this chapter will be dedicated to a particular phenomenon cross-linguistically attested which represents an exclusive case in color domain: the semantics of blue.

1.4. The blue spectrum: a linguistic-perceptual phenomenon

Color domain has been at the center of the question and controversy concerning the impact of language on perception for a long time (Whorf 1956; Gumperz and Levinson 1996; Gordon 2004; Miozzo and Gordon 2005; Casasanto and Gordon 2005; Kay and Kempton 1984); Roberson and Davidoff 2000; Witthoft et al. 2003; Heider 1971; Heider and Olivier 1972; Lindsey and Brown 2002; Franklin et al. 2005).

Humans' finesse allows the discrimination of up to two millions of colours, varying in shade and hue, which are grouped in color categories (Regier and Kay 2009) whose nature, perceptual or linguistic, has been largely debated (Regier, Kay, and Cook 2005; Franklin and Davies 2004; Roberson, Davies, and Davidoff 2000; Regier, Kay, and Khetarpal 2007; Yendrikhovskij 2001). Some authors have supported the hypothesis that color categories influence the attentional and cognitive processing in perceptual color judgments (Hanley and Roberson 2011; Clifford et al. 2012; Holmes et al. 2009; Thierry et al. 2009; Clifford et al. 2010; Mo et al. 2011), whereas others have suggested that color perception can be not categorical, but defined by sensory patterns lacking categorisation (Brown, Lindsey, and Guckes 2011).

In this multidisciplinary field of study, the color blue occupies a special place. It has been observed, indeed, a common behaviour across several languages that partition the blue color space in a special way, through a distinction on lightness. The blue hues are, thus, linguistically marked by two distinct terms: one for the light blue and one for the dark blue.

At the same time, as we explained in the previous section, the green-blue chromatic boundary in the color space has been one of the most studied because of its specificity. From a diachronic point of view, the evolutionary studies made on this color boundary have allowed researchers to refine some central assumptions, as the case of Berlin and Kay's explanations on cross-language variations in categorisation. For this reason, the blue hues, frequently in opposition to green hues, have been used in different experimental

protocols to test various aspects of the language-perception mutual dependence/independence.

1.4.1 The exception of blue: cross-language variations in the color space partitioning

The color blue, conventionally and prototypically associated with the sea and the sky, is considered extremely salient in several cultures that languages have sometimes developed a specific chromatic vocabulary to convey the multiple meanings (Uusküla 2009).

Different basic color terms have, indeed, emerged denoting the various types of blue related to the corresponding color categories. This refinement has been attested in a considerable number of languages, belonging to the Mediterranean area, to the Uralic family and to the Slavic region: for instance, Italian, Russian, Turkish, Greek, Maltese, Catalan, Polish, Ukrainian, Belarusian, Lithuanian and Udmurt have two separate salient word for BLUE, one for the dark blue and one for the light hue (Giacalone Ramat 1967; Grossmann 1988; Paggetti, Bartoli, and Menegaz 2011; Paramei, D'orsi, and Menegaz 2014; Sagaspe et al. 2006; Sandford 2011; Davies and Corbett 1994; Paramei 2005; Thierry et al. 2009; Athanasopoulos 2009; Borg 2011; avies, Corbett, and Margalef 1995; Özgen and Davies 1998; Putzu 2000; Coventry et al. 2006; Rätsep 2011, 2012; Davies, Corbett, and Margalef 1995). Japanese integrates this set of languages, too (Kuriki et al. 2017).

Before presenting the case of Greek, Russian, Japanese and Italian, which will be discussed in detail in the next sections of this chapter, it is relevant to mention some studies which have used the blue color special character to examine perceptual and/or linguistic mechanisms underlying color perception in general.

One of them is that of Gilbert and colleagues (Gilbert et al. 2005) who analysed the whorfian effect of brain lateralisation through a visual search task. A cercle composed of

coloured squares tied from a set of four, falling in the green-blue boundary, was presented to English native speakers' participants. On each trial, all the squares have the same color except for one (the target) which can either belong to the same lexical category (for example, two shades of blue) or to a different lexical category (for example, one green and one blue). Subjects had to indicate whether the target square was in the left or in the right of a ring of coloured chips with the corresponding hand, as quick and accurate as possible.

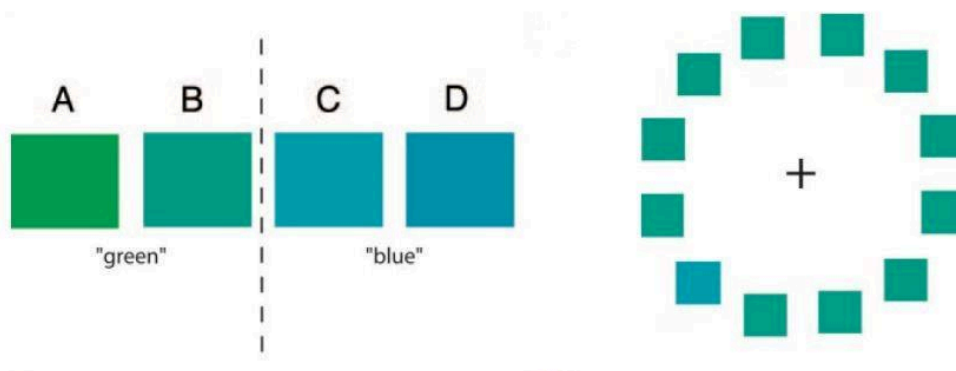


Figure 20: Visual Search task material and procedure (Gilbert et al. 2005).

Samples of the four coloured squares used in the task and model of a visual search task's trial.

This task was also performed with the addition of two interference tasks, one verbal and one spatial, to analyse whether language affects perceptual discrimination through the automatic and spontaneous use of the lexical system. Gilbert and his scientific team's results have, in fact, shown an effect of categorical perception of color (e.g. faster RTs for targets in the right visual field compared to the targets in the left visual field) which was disrupted in the conditions of verbal interference (Kay and Kempton 1984; Roberson and Davidoff 2000; Witthoft et al. 2003), but not in the tasks involving the spatial working memory. Moreover, the authors replicated the experiment with a callosotomy patient to

analyse the hemispherical involvement in color perception and language processing, in order to understand the selective language modulation in the LH/RVF, too.

The results of all these experiments established that the laterality effect was associated to the hemispheric asymmetry since color lexical codes influenced color perceptual discrimination in the right visual field (left hemisphere), but not in the left visual field (right hemisphere). The authors, thus, concluded that the effect of language can be multiple: either color discrimination is directly impacted by language, altering the nature of early visual responses, especially in the LH, or language has a facilitatory effects on post-perceptual processes which lead to a stronger effect of categorisation in the left hemisphere.

Other studies employing different shades of blue for linguistic/perceptual analysis are those of Jarvis on conceptual transfer (Jarvis 2011) and that of Bird and colleagues on the neurophysiological basis of color categories encoding (Bird et al. 2014).

Jarvis examines some cases of cross-linguistic influence in the domain of conceptual transfer (the effects of cognitive structures acquired through one language on the use of another language), observing the categorisation processes in mental categories and lexicalized concepts in different domains. One of the works taken into consideration is the study conducted by Athanasopoulos and his colleagues (Athanasopoulos 2009; Athanasopoulos and Kasai 2008) on color categories perception in Greek-English bilinguals, which was based on previous research on Japanese- English bilinguals (Kuriki et al. 2017). In the two cases, the authors analysed the two lexical distinctions, in Japanese and Greek, in the blue categorisation of color space in order to determine the color perception of the salient blue hues in proficient bilinguals. Jarvis evaluated their findings as a proof for conceptual transfer strategies in situations of cross-linguistic influence, showing that speakers of different languages with different linguistic patterns related to conceptualisation and/or categorisation, can be extended in the use of another language lacking this specific pattern.

On the other hand, Bird, Berens, Horner and Franklin (Bird et al. 2014) analysed the neural populations representing color categories through fMRI. They used an experimental design where two colours, either from the same category (e.g., B1 and B2) or from different categories (e.g., G1 and B2), were presented successively: participants had to detect a target, regardless of the color differences. Their four stimuli were composed by colours varying in the hue such as three of them were expected to be named as blue hues and the fourth one as a green hue. A naming post-experimental task confirmed the expected lexical-perceptual boundaries, as shown in figure 21.

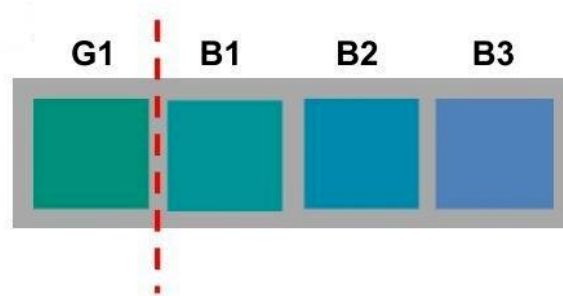


Figure 21: The four colours used in the fMRI experiment (Bird et al. 2014).

The dashed line defines the blue-green lexical boundary made by most of the participants

It is evident that the choice of the green-blue boundary for these works is not arbitrary: several domains have used it because of its peculiarity and the possibility to explore various aspects of color perception, from lexical distinctions to categorical brain processing. The blue and green boundaries are, indeed, continuous color boundaries in the chromatic spectrum; for this reason, some languages, like Tarahumara, a Mexican language, do not distinguish between blue and green from a linguistic point of view. Moreover, the distinction between light green and dark green has been used to compare the two lexical discriminations detected in the blue category to the green ones in order to determine whether this distinction appears in the green category, too. No salient results have been shown.

Therefore, in the next section we will try to give an exhaustive overview of the linguistic phenomenon affecting perception emerging in the blue spectrum partitioning of some languages, notably Japanese, Greek and Russian.

1.4.2 Lexical-perceptual distinctions in the blue hues: the case of Greek, Japanese and Russian

Language variations in color space partitioning have been particularly studied in the green-blue boundary, especially in Greek (Athanasopoulos 2009), Turkish (Özgen and Davies 1998), Japanese (Uchikawa and Boynton 1987; Kuriki et al. 2017), Russian (Winawer et al. 2007) and Italian (Bimler and Uusküla 2014; Uusküla 2009; Paggetti and Menegaz 2013; Valdegamberi, Paggetti, and Menegaz 2015). These languages, in fact, linguistically discriminate two perceptual hues in the blue chromatic area, one for light blue and one for dark blue: the peculiarity of the phenomenon, absent in other languages like English or French, is that the two terms have both acquired the status of BCTs. The lexical partitioning has an impact on cognition in general, and visual perceptual distinction in particular (Athanasopoulos et al. 2015).

Moreover, since attention is manipulated by some language-specific concepts focusing more on certain features than on others, bilinguals represent a challenge for the debate on the language-cognition mutual influence: the bilingual concepts, which are relied to two distinct linguistic partitionings of the physical color continuum, can be impacted by the differences in the lexical systems (Green 1998; Pavlenko 2005). Experimental studies have been conducted in several domains to investigate this effect (for example, the grammatical number and object classification (Athanasopoulos 2006, 2007; Cook et al. 2006), emotion (Pavlenko 2005, 2006), time (Boroditsky 2001), gender (Boroditsky and Schmidt 2003) and others). One of them is the cognitive representation of colours. Various researches have, thus, examined whether the knowledge of two or more languages, differing in the color space encoding, can affect perceptual color discriminations, as well

as the possibility of a cognitive and/or semantic shift in bilinguals (Athanasopoulos 2007; Athanasopoulos and Kasai 2008).

As we will explain in more detail in the next chapter, the second language can cause a shift in the way color prototypes are used and defined in the first language color words, especially when bilinguals are highly proficient in their L2 (Ervin 1961; Caskey-Sirmons and Hickerson 1977; Zollinger 1988b; Jameson and Alvarado 2003; Sayim, Jameson, and Alvarado 2003). For this reason, some researchers have affirmed that “the worldview of bilinguals, whatever their first language, comes to resemble, to some degree, that of monolingual speakers of their second” (Caskey-Sirmons and Hickerson 1977, p. 365).

Therefore, the works on bilinguals always analyse their monolingual counterparts in order to provide additional empirical evidence to the assumption that bilingual speakers of languages which differ in their lexical categories and concepts represent these categories differently than the monolingual speakers of their L1, making a cognitive shifting towards the monolingual speakers of their L2. L2 color categories can, thus, influence both the representation of the L1 color categories on the color continuum and their perceptual discrimination. In bilinguals, the double set of categorical divisions can restructure the cognitive assessment of the first language according to the second language’s lexicon (Cook 1997; 2002, 2003; Green 1998; Pavlenko 2005, 1999).

One of the more studied languages for the investigation of the bilingual language and cognition interaction is Greek. Athanasopoulos (2009) has, indeed, conducted behavioural experiences to examine the bilingual consequences on perception and cognitive representation of color categories. He started from the lexical distinction observed in Greek in the blue region of color space: two words, *ble*, for dark blue, and *ghalazio*, for light blue, are, in fact, integrated to the set of Greek basic color terms. Athanasopoulos tested Greek-English bilinguals in a similarity judgment task where light and dark blue stimuli were presented to the subjects. He also measured other bilingual variables that are supposed to impact the performance, such as L2 proficiency, the L2 age of acquisition, the amount of time spent in a L2-speaking country, the amount of time spent using the L2, as well as the L1 and L2 color words semantic memory. His results have shown that these factors play a central role in the judgment task of perceptual differences of different

shades of blue, with the possibility of cognitive shifts for salient terms, like *ble* for *ghalazio*.

The two Greek blue basic terms have been analysed also from a neurophysiological point of view by Thierry, Athanasopoulos and their colleagues (Thierry et al. 2009), who, through an oddball shape discrimination task (figure 22), tested English and Greek monolingual speakers. They recorded brain potentials to observe the impact of the native language on unconscious and preattentive aspects of perception in four blocks: in two experimental blocks the stimuli were light or dark green and in two other experimental blocks the stimuli were light or dark blue. Stimuli can have the shape of a square or of a circle and subjects had to press a button when they saw the stimulus with a different shape (the target). However, stimuli can differ in the luminance color (the deviant), too (light blue vs dark blue and light green vs dark green).

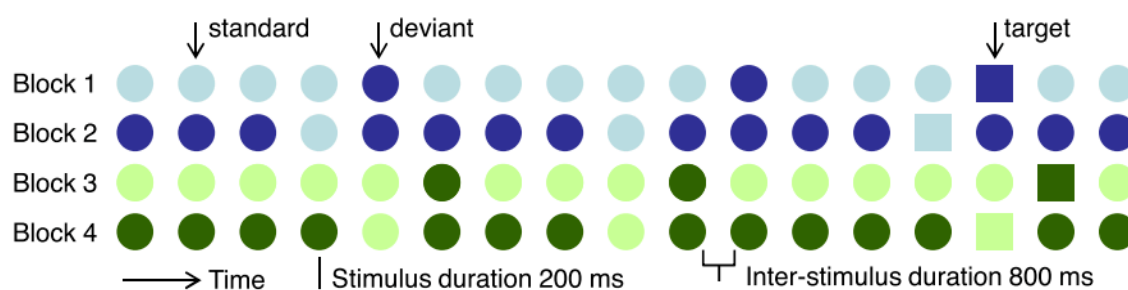


Figure 22: Experimental design and stimuli sequence in the four blocks (Thierry et al. 2009)

The authors expected a greater vMMN effect for blues in Greek participants compared to English ones since the existence of two basic color terms for light and dark blue in Greek would make Greek speakers more sensitive to luminance deviants in the blue blocks than in the green blocks since they were perceived them as more different. The vMMN results confirmed that a greater distinction between different shades of blue compared to different shades of green exist at a neurophysiological level in Greek speakers; this effect is absent in English speakers, who exhibited any distinction.

Therefore, an effect of the native language on preattentive color discrimination and unconscious cognitive processing in color perception is detected through electrophysiological differences, enregistered also in the primary and secondary visual cortices (Mangun et al. 1998). Lexical specific distinctions between two color shades in one language, thus, affect early visual processing and color perception, in addition to higher level of categorisation (Thierry et al. 2009).

These works (Athanasopoulos 2009) on Greek blues have been the base for additional studies in other languages: it is the case of Japanese which is part of the group of languages marking the light-dark blue distinction with two basic color terms. The researches on this issue have investigated the color categories perception by Japanese-English bilinguals in perceptual tasks (Athanasopoulos et al. 2011) and by a Japanese monolingual color naming task (Kuriki et al. 2017).

Kuriki and his colleagues (Kuriki et al. 2017) replicated a quantitative color naming study conducted 30 years before by Uchikawa and Boynton (1987) to show that, in the meantime, three non-basic color terms have acquired the status of BCT. One of these words was *mizu* (light blue), which was added to *ao*, which defines the dark blue. Through a comparing approach, the authors put evidence on the evolution of the Japanese color lexicon, analysing the statistical number of significant named chromatic color categories as well as their extensions across color space. Kuriki's results diverged from those of Uchikawa and Boynton: since the consensus for *mizu* was very high, they can argue that light blue has become a new color category linguistically specified by a new BCT in Japanese. Japanese has, thus, been added to the set of languages, belonging both to the Indo-European family and to non-European linguistic families, marking the distinction for light blue and dark blue through two basic color terms.

The basicness of *mizu* and *ao* has been also experimentally tested by Athanasopoulos and his colleagues (Athanasopoulos et al. 2011). They notably investigated how concepts that are language-specific, are treated in the bilingual cognition, testing Japanese-English bilinguals in the perceptual distinctions of dark blue and light blue. One of the main interests of this study is the analysis of the impact of linguistic and extra-linguistic factors on color cognition in bilinguals since specific linguistic categories that describe cognitive

patterns can differ cross-linguistically. The bilingual group tested was, in fact, composed of individuals with different daily linguistic experiences depending on their duration of stay in an English-speaking country. Two control groups, one formed by English monolinguals, and one formed by Japanese monolinguals, have been submitted to the experimental test, too.

Athanasopoulos (2009) had already argued that the semantic memory for specific lexical distinctions and the length of stay in an English-speaking country have an important impact on the use of color precise terms since, the more participants have lived in an anglophone city, the more their linguistic categories were reinforced.

In the study conducted in 2011 (Athanasopoulos et al. 2011), the authors examined the categorical perception of color in late proficient bilinguals who have been expected to perform as monolingual speakers of their L2 in a perceptual discrimination task. Their proficiency was, in fact, correlated to a cognitive shift towards their L2, indicating cognitive flexibility. They also evaluated perceptual distinctions of colours depending on the language they used the most in their daily life: bilinguals who mainly used English performed more similarly to English monolinguals, whereas bilinguals who mainly used Japanese performed more similarly to Japanese monolinguals. Therefore, the results of the work showed that bilinguals who regularly used Japanese distinguished more subtly and easily the two blue hues than those who used English more often.

In this study, the perceptual task consisted of a pair of blue squares presented on the screen varying in hues (10 different hues in total): subjects were asked to define the degree of similarity of the two colours on a scale of 1 to 10. The 10 hues used have previously been described by Japanese speakers as *ao* or *mizu*. The authors found that Japanese monolinguals tended to judge two colours to be more different if they fell into distinct linguistic categories, one in *ao* category and the other in *mizu* category, compared to pairs of colours belonging to the same category. On the other hand, English monolinguals did not show any categorical effect on the perceptual distinction and Japanese-English monolinguals exhibited an intermediate cognitive pattern. Their performances, in fact, depended on the frequency of use and exposure to the L1 and the

L2, denoting that mastering linguistic systems which partition and categorize reality differently, has a deep impact on cognition.

However, despite the results of this study have provided some support to the linguistic relativity hypothesis, showing that objective similar constructs are modulated by linguistic categories in different ways varying cross-linguistically, there are some limitations that cannot be ignored. Two main constraints are, for example, the limited set of stimuli used and the effect of the verbal response in the manipulation of colors' perceptual distance judgment (Athanasopoulos et al. 2011).

1.4.2.1 Studies on the Russian blues: a starting point for the current work

Like Greek and Japanese, Russian is one of the languages that have two contender words categorizing the blue region: *sinij* for dark blue hues and *goluboj* for light blue hues (Vamling 1986; Corbett and Morgan 1988; Davies and Corbett 1994). They all, thus, represent an exception to the theory of Berlin and Kay supposing a maximum of eleven basic color terms with the possible redefinition of conceptual color categories.

However, despite the other languages marking this distinction, Russian occupies a special place in the color categorisation domain: several studies belonging to different fields (linguistics, anthropology, ethnography, psychology, cognitive sciences) have, in fact, been made for several years. All the researches (Paramei and Cavonius 1999; Dedrick 1998; Eco 1985; Hardin 1988; Kay and Maffi 1999; MacLaury 1997) have analysed different aspects of this phenomenon, like the semantic segmentation, the mechanisms driving the color terms categories evolution, the impact of cultural specificity or the place of the neurophysiological functioning of the visual system.

The Russian lexical categorical distinction between light and dark blue had an impact on neighbouring languages, like Lithuanian, Udmurt, Ukrainian and Belarusian, too (Hippisley 2001; MacLaury 2001; Bimler and Uusküla 2017; Uusküla and Bimler 2016). Intensive

language contacts, language influence or domination have, in fact, led to the emergence of new perceptual distinctions in color boundaries.

In this section, we will review some of the findings coming from different works of various disciplines which have tried to explain the contentious status of the two Russian blues, discussing further developments of the BCTT. One of them is the study of Moss, Davies and colleagues (Moss 1989; Moss et al. 1990) who conducted a color naming task with Russian-speaking participants to verify the basicness of certain color terms, including the two words for *blue*. Their experimental design was inspired by the work conducted by Boynton and Olson in 1987 on English subjects and by that of Uchikawa and Boynton (Uchikawa, Uchikawa, and Boynton 1989; Boynton, Maclaury, and Uchikawa 1989) on Japanese-speaking subjects, through the analysis of both linguistic and psychological factors, like the naming reaction times, the frequency of occurrence, the degree of consensus and the degree of consistency. Their results confirmed the assumption that basic terms are named faster and more frequently than non-basic terms, as well as consistent and consensus responses compared to inconsistent and non-consensus responses, which have faster mean reaction times. Their data, thus, provided also a confirmation for the basicness of the two Russian terms for *blue* since *sinij* and *goluboj* had a high rate of response, frequency and fast RTs without any confusion between the two terms in any part of the blue color spectrum.

The basicness of the two Russian blues has been tested by Davies and his colleagues (Davies et al. 1998; Davies 1998), too. They specifically focused the attention on the acquisition order of color terms by children in order to verify the paradigm proposed by Berlin and Kay (1969) who suggested that the infants' acquisitional order of the basic color terms follows the hierarchical order of the emergence of basic color terms in one language, because of their frequency of use and their perceptual salience. The authors, thus, tested Russian-speaking children aged from three to six in three behavioural tasks (a color term listing task, a color term production task and a color term comprehension task): their data confirm the Berlin and Kay's theory on the order of color terms acquisition, as well as the assumption that primary terms tend to be learned before derived terms. Moreover, results were consistent with the Russian exceptionality in the color lexicon (twelve basic color terms): the two terms for the blue region are both

acquired and used as two basic terms, even though the phenomenon is less visible than in adult data.

Other linguistic and psycholinguistics studies on the refinement of the Russian blue area, conducted by different research groups (Frumkina and Mikhejev 1983; Frumkina 1978, 1979, 1999, 1984; Taylor and MacLaury 1997; MacLaury 1997, 2002; Morgan and Corbett 1989; Davies and Corbett 1997; Davies, Corbett, and Margalef 1995; Korzh, Penova, and Safuanova 1991; Corbett and Morgan 1988), are also been reported by Paramei (2005) in the article *Singing the Russian blues: An argument for culturally basic color terms*, where she reviews some of the most relevant ones in this field of study. For example, the group of Frumkina and her colleagues (1978, 1979, 1984) have directed various experiments (e.g. sorting color terms tasks or mapping color foci tasks) which attested the basicness of *goluboj* and of *sinij* on the basis of the two blue clusters' distinction, as well as their separation on the respective foci distribution. The authors (Frumkina 1984; Frumkina and Mikhejev 1983) also observed that the distinction between *goluboj* and *sinij* mainly relied on differences in lightness.

The group of research of the University of Surrey is another one presented by Paramei (2005). The authors (Corbett and Morgan 1988; Morgan and Corbett 1989; Davies, Corbett, and Margalef 1995; Moss et al. 1990; Laws, Davies, and Andrews 1995; Davies et al. 1991) used different types of experimental designs to investigate the frequency of color terms, the degree of derivational morphology, different factors of the psychological salience (frequency of occurrence, reaction times, degree of agreement, consistency of use), as well as the *goluboj* and *sinij* mapping in the blue area of a color space and the effects of color boundaries categorisation. Globally, all the results collected by these experiments provided strong empirical support for the assumption that Russian has twelve basic color terms.

Moreover, focal colours and semantic boundaries have been tested by a group of psychology of Moscow (Korzh, Penova, and Safuanova 1991; Korzh and Safuanova 1994) who obtained the same results as the Surrey group, demonstrating that the *goluboj* and *sinij* foci are mapped in distinct areas of the color space, even though the size of the respective boundaries is not the same. *Goluboj* covers, in fact, a larger area than *sinij*.

However, the study of Korzh and Safuanova (1994) on the achromatic modifiers, like the English *pale*, *dark* and *bright*, revealed that the two blue categories overlapped when achromatic modifiers were employed.

Among all these works conducted on the Russian blues, the study of Winawer and his colleagues (Winawer et al. 2007) occupies a special place for the current study. It is, in fact, the starting point of our subject questioning and the model of our experimental protocol, described in detail in the next chapters.

Winawer and his research group aimed to analyse the online involvement of language in an objective color discrimination, even when cross-linguistically differences in a specific color boundary are detected. They, thus, conducted an objective color discrimination task with two groups of participants belonging to languages which differently categorise the blue area in a color spectrum: English and Russian. Their hypothesis was that the two language groups can differ in their perceptual discrimination performance across this boundary, absent in English, and that language can alter only the performance of the group making the linguistic distinction (Russian).

The authors chose a simple objective perceptual procedure with minimal memory demands in order to avoid that any subjective judgments or intensive memory procedures come into play during the perceptual task. They, in fact, showed a triad composed by three coloured squares presented simultaneously on the screen to participants: the task was to manually say, pressing the corresponding button, which of the two squares on the bottom was identical to the square on the top (on the left or on the right). The stimuli were twenty colours ranging from dark blue to light blue (the Russian distinction between *siniy* and *goluboy*): the match and the distracter, the non-matching square, could come from the same Russian category or to two different categories. However, since for English participants this category distinction was absent, all the stimuli belonged to the same linguistic category (*blue*).

To test the role and the impact of linguistic processes during perceptual tasks, Winawer and his colleagues added two interference conditions during the task: one verbal and one

spatial. If language has an online involvement during an objective task, this effect should diminish the category advantage effect in Russian speakers during the verbal dual task, but not during the non-verbal dual task, used as a condition control. A category effect was, in fact, detected during the perceptual task for Russian participants but not for English participants: Russian were faster and more accurate in the discrimination of two color falling into different linguistic categories than when the two color fell into the same linguistic category (both *goluboy* and both *siniy*). In the first case the discrimination was easier, since the two stimuli were more perceptually dissimilar (far-color comparison), whereas in the second case the finer perceptual discrimination made the task more difficult (near-color comparison).

Winawer's results confirmed the assumption that the Russian category advantage disappeared during the verbal double condition task, but still remained during the spatial double condition task; this effect was more marked for finer discriminations. On the other hand, English participants did not show any category advantage in any experimental condition. Therefore, the performance of color perceptual discrimination task can be affected by linguistic categories, demonstrating an online involvement of language, and these language-specific categories varying across languages are active in perceptual decisions, exerting an influence.

The data of this study provide also evidence for the functioning of language impact on perceptual performance: linguistic representations interfere, in fact, spontaneously during these kinds of tasks. When the normal access is obstructed, as during the verbal interference condition, the effect of language-specific differences in perceptual discrimination disappear, too. Winawer and colleagues (Winawer et al. 2007) have, thus, taken part in the debate questioning the impact of language on non-linguistic processes, proposing the hypothesis that the language system is implicated in all kinds of extra-linguistic perceptual decisions, even when linguistic representations are not necessary to accomplish the task.

In conclusion, the segmentation of the blue area indicates a richness of different terms in many modern languages (Vasilevich 1987) with the possibility of further semantic refinements in languages currently lacking the linguistic distinction between dark and light blue hues. A possible candidate could be, for instance, the modern English which may develop two basic blue terms, due to the presence of two distinct words in Old English which designated different shades of blue (Kerttula 2002; MacLaury, Paramei, and Dedrick 2007): *hauuiblauum* for blue-gray and *blæwen* for dark blue.

1.4.3 The blue color in the Italian chromatic lexicon

Russian is the best-known example of language whose color lexical inventory contains twelve BCTs, notably two basic words for the blue region of the color spectrum (Winawer et al. 2007; Davies and Corbett 1997).

Among the set of languages which appear to linguistically differentiate between light and dark blue hues, we find Italian. Several studies have, in fact, demonstrated that Italians use more than one word to name the blue color space whose characteristics reflect the Berlin and Kay basicness criteria (Giacalone Ramat 1967; Kristol 1979, 1980; Grossmann 1988; Ronga 2010; Valdegamberi, Paggetti, and Menegaz 2015; Uusküla 2014; Paggetti, Bartoli, and Menegaz 2011; Paggetti and Menegaz 2013; Paramei, D'orsi, and Menegaz 2014): *azzurro* for light blue and *blu* for dark blue; a third word, introducing the medium blue nuance, has been identified too: *celeste*.

Cultural and historical factors can partly explain the Italian lexical differentiation, but psycholinguistic studies, color naming and color listing tasks have confirmed, through various types of color stimuli and experimental methods, the basic status of these color words, as well as the extent of their intra and inter-subjects' agreement.

In this section, we will present some experiments of different nature which compared varied sets of stimuli, following the OSA-UCS color order system or the Munsell Color

System, and used different empirical methods (e.g., monolexemic color naming, constrained or unconstrained color naming). Their results globally attested the salience of centroids or focal colours corresponding to the color words for the two blue hues (Lindsey and Brown 2014; Boynton and Olson 1990; 1987; Sturges and Whitfield 1995, 1997; Guest and Van Laar 2000; Lin and Shum 2001; Safuanova and Korzh 2007).

The investigation of the properties of the Italian BCTTs will allow us to explore the evolution of the Italian semantics, as well as the psychological salience of the two Italian blues with the emergence of the twelfth BCT *azzurro*.

1.4.3.1 The Italian blues: from *Blu* to *Turchino*

Theoretical and empirical studies have demonstrated that in the Italian color lexicon we find up to three color words to name the blue area: *blu*, *celest*e and *azzurro* for dark and light blue hues (Paggetti, Bartoli, and Menegaz 2011; Paggetti and Menegaz 2013; Bimler and Uusküla 2014; Uusküla 2014). *Azzurro* mainly corresponds to medium light blue, whereas *celest*e corresponds to light blue. Research analysing the three terms' respective employment and status in the lexicon reservoir has been conducted in recent years: their results have shown relevant aspects which justify the weak hypothesis of the Berlin and Kay BCTT (Giacalone Ramat 1967; Kristol 1979; Grossmann 1988; Ronga 2010; Boroditsky, Schmidt, and Phillips 2002; Valdegamberi, Paggetti, and Menegaz 2015; Paggetti, Bartoli, and Menegaz 2011; Paggetti and Menegaz 2013; Bimler and Uusküla 2014).

One of them is the work of Paramei, D'Orsi and Menegaz (2014) who used eight Munsell color charts of the blue chromatic area to test the differences between Italian speakers and English speakers in an unconstrained color naming task. Focal colours of *blu*, *azzurro* and *celest*e for the Italian groups and focal colours of dark blue and light blue for the English group have been tested, too. The Italian subjects came from two different regions (Sardinia and Veneto): this choice is explained by the fact that previous studies have

already shown that the three words have different status across Italian dialects. In fact, the authors' findings indicated that for the Sardinian speakers, *azzurro* was mostly used to name medium blue hues and *celeste* was used for naming light blue, whereas the Venetian speakers mostly used *azzurro* for both light and medium blue shades, leaving aside the word *celeste* which often overlapped with *azzurro* and was less frequently used. General consensus on the status of the word *blu* denoting dark shades of the blue area have been detected for the two Italian groups.

This study adds evidence to the assumption that in Italian there exists two basic color terms for the blue area which is differentiated along the lightness dimension: *blu* and *azzurro*, whose cognitive representations and focal colours are distinct. The third word *celeste* can be considered as a contender for naming light blue hues, but it is marked across regional dialects and does not have all the characteristics required by basicness.

Another relevant study conducted on the three Italian blues is that by Uusküla (2014) who aimed to examine the intralinguistic and interlinguistic features of the blue Italian coding through tasks with both context-free and context-restricted color words usages. She tested Italian speakers in different experiments: a color naming test and a color listing task, a sorting task and an association task.

The first one, where frequency, position and cognitive salience have been calculated, allowed the identification of the Italian color lexical inventory as well as the status of the Italian blues. In the second one, the sorting task was followed by the identification of the focal colours, or prototypes, of the words *blu*, *azzurro* and *celeste*. Lastly, the third one analysed the impact of context in the linguistic categorisation of the blue area: participants had, in fact, to associate the three Italian lexemes (*blu*, *azzurro* and *celeste*) to a serie of nouns and adjectives in order to form correct and meaningful expressions.

The author's findings globally attested that Italians need at least two color words to categorize the blue area in the color spectrum, one for light blue shades and one for dark blue shades. The three terms *blu*, *azzurro* and *celeste* are salient with high agreement among participants about their mutual status: they are not, in fact, synonyms since each of them denotes specific color hues and is used in well-defined particular contexts. From

a cognitive point of view, the three lexemes are considered by Italian speakers as independent categories, too.

However, it is worth mentioning a remarkable point which has been detected in all the experiments: the word *blu* is the prevailing one with high degree of consensus, elicitation, naming frequency and salience (Sandford 2011). Therefore, *blu* may be considered as the main, strongest BCT in the blue area detoning a general name for the whole BLUE category; it is then followed by *azzurro* and *celeste* whose data have shown different results depending on the type of task and on extra-linguistic factors, like emotional connotations of words and the temperature (cold versus warm) of the chromatic stimuli.

The differentiation of the three Italian blues can, thus, be derived from linguistic and extra-linguistic factors. Cultural and historical features have probably influenced the Italian chromatic repertoire leading to the emergence of distinct color words for cognitive needs, notably linked to the definition of the colours of the sea and the sky (Uusküla 2014; Giacalone Ramat 1978). In the following section, a non-exhaustive explanation of this phenomenon is reported in order to highlight the interconnection of aspects of various nature and domains in the evolution of the Italian chromatic lexicon.

1.4.3.1.1 The impact of historical and cultural aspects on the blue lexicon evolution

In the history of the study of colours, specialists of different domains have tried to solve two interconnected problems: one involving the possibility to understand and systematize the chromatic perception, and one, more technical, relative to the artificial reproduction of colours. These two factors have been at the center of the comparison between, on one side, physical and perceptual studies and, on the other side, socio-cultural analysis (Hardin 1997). All the results coming from this research bring relevant characteristics of the same chromatic phenomenon as well as of its linguistic categorisation.

For this reason, we will discuss some cultural and anthropological factors which had an impact on the evolution of the Italian color lexicon in the blue area. One of them is the production and diffusion of dyeing made by a specific society: the vocabulary of one language is strictly linked to technical developments since, for the case of chromatic words, it would seem that they emerge as a consequence of the need to define the artificial colours that a society can produce, rather than as a need to describe the natural world (Ronga 2010). Therefore, chromatic categorisation and the cross-linguistic variations can be determined by some aspects of the social context.

Considering the Italian exception in the chromatic categorisation of BLUE, historical and typological factors may have played a non-negligible role for the actual status of the two Italian BCTs *blu* and *azzurro*. In fact, Italy is geographically placed at the crossing point of two kinds of categorisation of the blue spectrum, notably between countries whose language does not linguistically mark the distinction between dark and light blue, like French, and countries whose language has two distinct terms, like Catalan in Spain. From an historical point of view, in fact, the chromatic words are mainly linked to a concrete referent, typically a pigment; its semantic extension and diffusion, thus, depends on the availability of the corresponding pigment (Ronga 2010).

In the case of the two Italian blues, the status of the two terms reflects historical conditions: *azzurro* entered in Italian with the Savoy House expansion in the North of Italy: this color gradually evolved in its use and its denotata, symbolizing the royalty. In contrast, *blu* is a loan from French which appeared in Italian later than *azzurro*, probably in the 17th century, to denote a darker blue shade, because of the import of indigo in the North Italy (Kristol 1979; Pastoureau 2001; Giacalone Ramat 1967; Paggetti, Menegaz, and Paramei 2016).

At the beginning of the Italian chromatic lexicon history, *azzurro* has, thus, a higher status than *blu*: it is not included in the blue semantic sphere, it can be used to denote several kinds of different concrete objects and it is psychologically salient. Moreover, from an etymological point of view, *azzurro* was already known by Romans, especially used to denote lapis lazuli, since the origins of the word are Persian. On the other hand, *blu* is a Germanic word, recently borrowed by French, whose first testimonies showed that it

indicated lighter shades of blue. The chromatic tendency was, thus, reversed compared to nowadays.

Over the centuries, the Italian vocabulary of colours have evolved and the two lexemes have changed in status and specialized their respective semantics: for instance, the increased frequency of use and the extended denotata of *blu* during the 20th century are probably due to the great quantity of loans and calques by other languages marking the BLUE category with a single central word, like French and English (Silvestre, Cardeira, and Villalva 2016; Dębowiak and Stala 2016). Moreover, additional color terms for the BLUE categorisation have emerged, notably *celestes* and *turchino*. Dębowiak and Stała (2016) have analysed the contemporary use of the four lexemes (*blu*, *azzurro*, *celestes* and *turchino*) within the diachronic perspective of the historical evolution in written Italian. Their results meet some of the previous assumptions we have already mentioned. First, *azzurro* and *blu* are the more dominant ones and they possess all the criteria evoked by Berlin and Kay to be considered as basic color terms, with a marked presence in compounding and derivational constructions as well as in figurative and idiomatic expressions. In contrast, neither *celestes* nor *turchino* have acquired the necessary characteristics to have the status of BCTs. In fact, even though *celestes* is semantically transparent and can be morphologically decomposable, it rests peripheral compared to *blu* and *azzurro*; however, *turchino* is less transparent, despite the possibility to be morphologically decomposable. Its usage was, thus, already limited in ancient years and today it has fallen into disuse.

To conclude, the analysis of the chromatic phenomena requires the simultaneous study of different parameters (Bazzanella 2008) belonging to various fields of research. To track down one language chromatic categorisation schemes, linguists and neuropsychologists need, in fact, to take into consideration the historical and social features likely to influence the chromatic vocabulary, in order to seal them off their study. Furthermore, the need to consider a great number of factors is consistent with the complexity of the chromatic phenomenon, whose emergence includes neurological, perceptual, physical, social and historical aspects to be considered all together within a convergent approach.

1.4.3.2 Light and dark blue in semantics: the twelfth Italian BCT *Azzurro*

Cognitive mechanisms mark color categories with linguistic labels: color naming strategies can be relied on perceptual and linguistic factors, but we still lack consensus on their predominant nature. This issue has often been analysed in the context of the weak relativist hypothesis which proposes the possibility of the emergence of more than eleven basic color terms in some languages, especially in the BLUE category (Coventry et al. 2006; Özgen and Davies 1998; Paramei 2005; Winawer et al. 2007; Borg 2011).

As we already said, the case of the multiple Italian blues has been investigated by different specialists of the color domain in recent years, with the aim to provide results in favour of the twelfth BCT *azzurro*. Paggetti and Menegaz (2012, 2015) have, for example, conducted various kinds of studies focusing on both perceptual and linguistic aspects of color perception in the blue area of the color spectrum, which supported the theory that, in Italian, there exists a color category for light blue which is labeled by a lexeme that has all the features of a basic color term: *azzurro*. The authors tested Italian speakers in an unconstrained color listing and in a Stroop test (Paggetti, Bartoli, and Menegaz 2011; Stroop 1935; Sandford 2012; Paggetti and Menegaz 2012, 2013, 2015). The first one, the color listing task, intended to determine the recall frequency of the term *azzurro*: the recall frequency can, in fact, be considered as a measure of the basicness of a color word in the contrast between the semantics of basic and non-basic colours. On the other hand, the Stroop experiment, which will be presented in detail in the following chapters of this thesis, is designed to provide evidence of the twelfth color category. Based on previous results, speakers' reaction times should be longer when the ink of the color word *blu* is light blue (the correct answer is *azzurro*) than when ink of the color word *blu* is dark blue (the correct answer is *blu*). Different versions of the Stroop experiment have been conducted by Paggetti and Menegaz (2012, 2015) where different conditions were presented: congruent and incongruent stimuli, as well as various pairings of color words and color ink, in the blue and green color category. The green category was used as a

control category permitting the analysis of the exclusiveness, or not, of the blue category in the lexical and perceptual distinctions.

The color listing experiment data (Paggetti and Menegaz 2015) supported the assumptions that basic color terms are psychologically salient and highly frequent. However, the word chosen by Italian speakers to name the light blue hues was *azzurro* with a level of frequency similar to those of the other eleven basic color words, confirming the hypothesis that Italian has a basic term to designate the light blue area of the color spectrum. Moreover, data about the psychological salience of color words confirmed the basicness of the twelve basic color terms, including *azzurro*.

Moreover, all the Stroop experiments showed results that corroborated the thesis about the existence of two blue BCTs in Italian varying on the lightness dimension. The data globally attested that the color word *blu* is more rapidly named when it is written in dark blue ink than when it is written in other basic colours inks, including light blue ink. Therefore, reaction times are faster for stimuli pairing the color word *blu* and the dark blue ink, corresponding to *blu*, compared to stimuli where the color word *blu* was paired to light blue ink, corresponding to *azzurro*. In contrast, in the green control category, no differences have been detected for stimuli associating the color word *verde* to light green ink or to dark green ink.

The authors (Paggetti and Menegaz 2015) also observed that speakers named the light blue color more quickly when it was combined to the color word *azzurro* than when this color word was presented in dark blue ink, corresponding to the color word *blu*. All these findings, thus, globally attested that Italian subjects' reaction times are shorter when they name a dark blue ink associated to the color word *blu* than when they name a light blue ink associated to the color word *blu*; nevertheless, naming a light blue ink requires shorter time when it is paired to the color word *azzurro* than when *azzurro* is written in dark blue ink.

Moreover, another aspect investigated by the authors is the nature of the differences in reaction times: they notably wanted to determine whether they are mainly due to a perceptual effect or whether they are linked to linguistic strategies. In the first case, they would observe the same tendencies for the two color categories (blue and green);

otherwise, in the second case, they would detect two different trends for the two categories which would reveal distinct linguistic mechanisms influencing performances. The authors concluded that, since no significant difference was detected in the green color category between stimuli pairing the color word *verde* to dark green hues and to light green hues, the variations in reaction times in the blue category are mostly due to a linguistic influence. In fact, subjects freely named the dark and the light blue stimuli with two distinct color words (*blu* and *azzurro*), but they used the same color word *verde* for denoting dark green ink and light green ink.

In a more recent work, Paggetti, Menegaz and Paramei (Paggetti, Menegaz, and Paramei 2016) analysed the psychological salience and the frequency of monolexic color words in order to further investigate the Italian color categories, putting evidence on the theory that *blu* and *azzurro* are both used and perceived as basic color terms by Italians. The authors conducted two color-naming experiments where consensus, consistency, focal colours and centroids were analysed, the same four measures evaluated by Boynton and Olson (1987, 1990) and Sturges and Whitfield (Sturges and Whitfield 1995, 1997) whose study is a reference for Paggetti, Menegaz and Paramei (2016) who replicated it with some little variations (e.g. different collections of stimuli).

For the BLUE category, the results confirmed the hypothesis that Italian has two blues differing for the lightness value, where *azzurro* labels colours with high lightness and *blu* names colours with low lightness. At the same time, centroids and focal colours do not fully coincide since *blu* focals and centroids correspond to darker blue colours than *azzurro* focals and centroids which are lighter. Therefore, these findings represent an additional support for the weak relative hypothesis with the possibility for a language to linguistically refine the color space with differences in color discriminations, as well as the emergence of supplementary color category boundaries to the previous ones already accepted, as in the case of *azzurro*.

The two Italian blues, thus, also confirm the Berlin and Kay's partition hypothesis of color categories (Berlin and Kay 1969): existing categories can, in fact, be successively differentiated, from a perceptual point of view, through the distinction of specific colours.

When this differentiation becomes salient, it needs to linguistically label it through new terms which will acquire the status of BCTs, like *azzurro*.

1.4.3.2.1 Mastering two color systems: the Italian blues in bilinguals

Color perception and cognition are affected by color categories, linguistically defined by color terms and varying from one language to another. However, when an individual masters two, or more, distinct linguistic systems, which differently partition the color space, color lexicon, categories and color boundaries of the L1 can be modulated by the color categories of the L2.

Bilinguals, thus, represent a means to test the universalist and the relativist theory in the color domain. Bilingual color categorisation and naming are supposed to deviate from those of the corresponding monolingual languages under the influence of some central factors which drive color cognition. Among them, the most important ones (Athanasopoulos et al. 2011) are the proficiency level of the L2, the frequency of use of the L1 and L2 in the subject's daily life, and the language exposure to the L2 (e.g. the length of immersion in a L2-speaking environment). Research conducted on bilingual color categorisation, like that of Athanasopoulos (2009), Caskey-Sirmons and Hickerson (1977), Andrews (1994), Erwin (Erwin et al. 1961), Jameson and Alvarado (Jameson and Alvarado 2003), Alvarado and Jameson (Alvarado and Jameson 2002), and Sayim and his colleagues (Sayim et al. 2005), has globally shown that bilinguals have color categories less stable than their corresponding monolinguals, with a mixed, composite set of color words that incorporates color terms and naming tendencies of the two languages (L1 and L2) but which is not identical to neither. Moreover, the focal colours of their basic color terms' lexicon are subjected to a shift towards the basic color terms of the L2 monolingual speakers.

Athanasopoulos' work (2009) has been one of the most important studies on the BLUE categorisation in bilinguals, using color chips of the Munsell Mercator projection. His results, in fact, revealed that proficient Greek-English bilingual subjects produced a shift

of the *ble* (dark blue) focus towards the focus of *blue* of English monolinguals in the lightness dimension. At the same time, the *ghalazio* (light blue) focus deviates from the English *blue* focus since the distance between the two Greek blues was maintained, following a polarization on the lightness value.

Paramei, D'Orsi and Menegaz (Paramei et al. 2016) started from these data and conducted an additional study on the Italian blues comparing Italian monolinguals, English monolinguals and a group of Italian-English bilinguals living in Liverpool, tested in the two languages. Using an unconstrained color naming task, where color chips were extracted from the Munsell chart, they asked participants to name each color they saw with the most fitting color word, including compound words or modifiers. Then they also identified the focal colours of *blu*, *azzurro* and *celeste* for Italian and *blue* and *light blue* for English.

Through a contrastive approach comparing both the different groups (e.g., Italian monolinguals vs. English monolinguals, Italian bilinguals vs. English monolinguals) and the targeted color terms (e.g., *blu* vs. *blue*, *azzurro* vs. *blue*, *celeste* vs. *light blue*, and so on), the authors detected a lightness shift and a hue shift. The lightness shift is observed for the *blue* foci of bilingual speakers, which were perceived as darker than the Italian *blu* foci, whereas *azzurro* focals were similar to the English *blue* focals and *celeste* foci correspond to the *light blue* of English monolingual speakers. The authors explained the bilinguals' semantic shift of *blue* towards *blu* as a consequence of phonological and orthographic cross-linguistic analogies which might facilitate the concept mediation from L1 to L2 since the access to L1 meaning is easier and more direct than that of the L2 (Kroll et al. 2010). Therefore, for bilinguals the English *blue* is globally darker than the English monolinguals' *blue*.

The hue shift observed, mainly concerns the bilinguals' concept of *azzurro* which reveals a shift both towards the English monolinguals' *blue* with a more purplish hint and a deviation from the *azure* foci of Italian monolinguals.

All these findings attested the presence of a Whorfian effect in the domain of color perception and categorisation in bilinguals, with lexical labels having an impact on perceptual representations, under the pressure of additional factors, like proficiency and

duration of L2 immersion, which determine the functioning of the bilingual integrated mental lexicon.

Conclusions

Color is a salient aspect of humans' world perception and representations which cannot be neglected in the studies of various research domains. In fact, the perception of colours is a sophisticated phenomenon which brings into play several different components, either perceptual and linguistic.

From the analysis of physical and physiological aspects of the human eye to the strategies of categorisation of reality, in this chapter we have tried to give a global satisfying portrait of the place occupied by colours in our daily life. Even though further works are needed to explain various unsolved questions, we have well-defined information about all the values acting during the perception of chromatic hues.

In the theoretical framework centered on the debate between relativists and universalists, we saw that color domain occupies a special place, the reason why a great number of studies of distinct fields has been dedicated to its investigation. Inside this controversy, one of the main points which is still discussed is the impact of language categories on color cognition and perception. As a consequence, perceptual discrimination is determined by linguistic distinctions and color naming, which vary cross-linguistically. The most cited and investigated example in color categories' variations is BLUE: several languages, in fact, partition the blue region of the color spectrum through the discrimination of dark and light blue hues, which are linguistically labeled with two distinct color words. Italian is of them with the two BCTs *blu* and *azzurro*, in opposition to French which lacks this distinction.

These two languages are at the heart of the current study which, in the discussion involving cognition and language, also analyses the bilingual behaviour in order to empirically put further evidence to the assumption that linguistic categorisation and cognitive structures can influence perception, even in fully extra-linguistic tasks.

For this reason, bilingualism will be discussed in detail in the next chapter.

PART II: The State of Art

Chapter 2: The Bilingual Experience

Introduction

Bilingualism is a huge worldwide phenomenon which involves all countries, all social classes and all age groups. It occurs every time an individual needs to communicate in different idioms and it is connected to several factors: the languages' contact inside one country or region, the presence of distinct languages to write and speak within the same population, political, economic, religious migrations, the need to communicate in a common language (*lingua franca*), for personal reasons (marriage, professional obligations), and many others.

For several years, bilingualism has been identified with negative labels and its effects on children, their language development and their neuropsychological skills have been subject to pejorative judgments, even from specialists.

However, during the last decades bilinguals and bilingualism have gained the interest of several researchers of different domains and it is currently one of the main subjects of study in neurosciences. In fact, following the *Web of Science* report, between 1993 and 2012 there has been a real explosion of research on bilingualism, especially for studies analysing the biological basis of second language learning. Thus, bilingualism is now seen as a tool revealing the functioning of language, mind and brain.

In this chapter, we will try to give an overall satisfactory portrait of this phenomenon engaging more than half of the world population, which created several doctrinal debates. At an initial stage, we will present the theories defining bilingual people, as well as a short review of the bilingual's characteristics. In the second section, we will analyse the different kinds of bilinguals identified, followed by a comparison to monolinguals; in the third section, we will talk about first and second language learning, presenting some theoretical models and the question of the critical age. The fourth section is dedicated to the relation between bilingualism and cognition, followed by a fifth section where the most important studies on the bilingual advantage are illustrated. In the sixth section we will analyse the impact of bilingualism on cognitive control and the role of executive functions: in this part, we will expose the main models of processing of the bilingual language of nowadays. The chapter will end with some conclusions.

2.1 Who is bilingual? An ancient debate

Bilingualism is a complex, multi dynamic and multidimensional reality (Kail 2015). Thus, giving a fixed definition is almost an impossible task since it would mean providing solid answers to questions like *What does it mean to know two or more languages? Which level of expertise in both languages is required for being considered bilingual? How do we distinguish a bilingual speaker from a second language learner?*

Each individual mastering two or more languages has a specific linguistic history involving the ways, the contexts, the routes taken to learn all his or her languages and more other factors, like age, environment and social groups, which allow him/her to use these languages. Thus, bilingualism is not a categorical variable (Luk and Bialystok 2013).

Two main theoretical views dividing researchers in two opposing factions have been the heart of a long debate concerning bilingualism and the classification criteria of people speaking two or more languages. The first one is termed the monolingual view (François Grosjean 1989) and the second one is called the holistic view.

2.1.1 The monolingual view

According to the monolingual view, being bilingual means speaking and mastering two languages perfectly and in the same way, as they were both two mother tongues (Bloomfield 1970). It is globally accepted that the linguistic competence must be the same in the two idioms, which have to be acquired during childhood, since birth. During the 20th century, this restrictive view has been defended by a narrow group of linguists which stated that bilinguals are two monolinguals in one person.

As Grosjean (1989) explains, the strong version of this theory considers the bilingual as a person who has two separate language competencies which, in turn, are similar to the competencies of the corresponding monolinguals. This perspective comes from the monolingual models at the base of language studies, considered the models of the

“normal” speakers and hearers. In fact, the methods and strategies of analysis to study bilinguals and the bilingual functioning have been the same as those for studying monolinguals for a long time, without variations or adaptations. Tests used with bilinguals rarely consider the different needs and social functions of the two languages, resulting in inappropriate evaluation of bilinguals’ language skills and abilities.

The monolingual view is constructed on the idea that the “real”, ideal, perfect bilingual, as Bloomfield (1970; Kent and Bolling 1934) and Thiery (Thiery 1978) assumed, is somebody who is equally and perfectly fluent in his/her two languages. All the other people who use multiple languages in their everyday life, which represent the majority, are classified as “less bilingual” and put in an indefinite category. Thus, bilinguals are evaluated only for their linguistic fluency and linguistic balance.

The conviction that knowledge and use of two languages have negative effects on individuals’ cognitive functions and language development is another aspect linked to the monolingual view. For several years, parents have been discouraged from speaking different languages to their children or have been convinced to avoid their children learning another language than the official one of the countries where they lived.

In this perspective, the contact between the two languages is rare, too. Since the bilingual is considered as two monolinguals in one person, the two language systems are completely separate and independent; if there is a contact, it is the result of interference, which means careless language. For these reasons, linguists have not put the attention on phenomena like borrowing or code-mixing and code-switching, evaluating exclusively the grammatical competences of bilinguals with no interest in the interaction between languages. Only some years later, a new group of researchers explains that language competence can change in time, even the first language competence, that can be dominated or simply influenced by the new idiom acquired (Bloomfield 1984; Thiery 1978).

Thus, linguistic skills are as important as language use and functions, and people mastering multiple language systems have heterogeneous competences: the bilingual view considers all these aspects.

2.1.2 The holistic view

Many people using two or more languages in their everyday life don't have an equal and perfect mastery of their two languages. In fact, we find among them multiple different cases: locutors who learnt their second language during or after puberty, or even in the adulthood, locutors who are not able to speak or to write one of the two languages, and locutors who use their languages distinctly in different contexts and situations and with different people.

Thus, most researchers prefer a vague definition of bilingualism where they include subjects with very different levels and linguistic abilities in their languages. For some of them, a bilingual person is someone who can produce significant statements in two or more languages; others prefer a simpler definition, focusing on the alternating usage of two or more languages (Weinreich 1968; Mackey 1968). In any case, the regular use or practice of two languages has become a defining factor.

The holistic view proposes that the bilingual is not the sum of two monolinguals, but he/she is an “integrated whole which cannot easily be decomposed into two separate parts” (Grosjean 1989). Bilinguals have a unique communicative identity and a specific linguistic configuration where the coexistence of two or more languages is in constant interaction.

Since 1985 this new perspective is supported by several researchers of different domains and evolves during time: for example, Christine Deprez (Deprez 1994), Lüdi and Py (Lüdi and Py 2002), Kohl and colleagues (Kohl et al. 2008) all developed complementary definitions of the bilingual person. For Deprez, the bilingual is a communicative individual with the same characteristics of a monolingual, but with a multiple linguistic repertory that he/she uses depending on contexts and situations. Lüdi and Py put the attention on the original competence of bilinguals, which is not a simple addition of linguistic and grammatical features of the first and the second languages; whereas Kohl and colleagues insist on the coexistence of two languages in a constant interaction which creates a special identity, distinct from the monolingual one, characterized by a whole not decomposable.

Grosjean (Grosjean 1989) makes a provocative analogy between the bilingual and the high hurdler in the domain of track and field: just like the high hurdler has two kinds of competences (sprinting and high jumping), the bilingual develops multiple linguistic competences but as a whole individual. Nobody would compare the high hurdles to a sprinter or a high jumper since he/she would not reach the same levels of competences, even though he blends some characteristics of the two disciplines: he/she is a distinct athlete. The same is for the bilingual: he/she is not comparable to a monolingual since the properties and uses of the two linguistic systems depend on needs, contexts, domains, interlocutors and they can be used together or separately.

The two languages' needs, and uses are rarely the same, so it is quite unusual that the bilingual is symmetrically fluent in the two languages in all domains, contexts and with the same groups of speakers. He/she develops specific communicative skills that are sufficient in everyday life, using only one of the two, or more, languages or the two together, mixing them during the speech. Thus, the bilinguals' linguistic repertoire is different from the corresponding monolingual one and can't be evaluated through only one language. For this reason, the holistic view assumes that it is necessary to consider the bilinguals' specificities in analysing their competences, focusing the attention more on the speaker's ability to communicate in a certain context than focusing exclusively on grammar, as the monolingual view did.

2.1.3 Characteristics of bilinguals

2.1.3.1 The two speech modes

In their everyday life, all kinds of locutors must manage with different linguistic registers. We don't use the same words and syntactic structures to talk to a child, to a colleague, to a family member or during a conference or an interview. Choosing a register or another determines the selection of a specific vocabulary, grammatical constructions and extralinguistic factors, like prosody. This choice involves only one language for the monolingual speakers, whereas for bilinguals it is more complex: which language must be

used in the current communicative context? Does it involve only one language or the two? (Kail 2015).

Since in bilinguals the two languages are not separate, but in constant contact, Grosjean (Grosjean 1989) suggests that there exists a situational continuum (Figure 23) where the two extreme poles, or speech modes, are the total monolingual mode and, on the opposite site, the bilingual mode. Bilinguals walk on this continuum differently in intermediate positions: some may never reach the bilingual mode and others may never leave it (e.g., speakers living in multilingual communities where language mixing is the usual habit).

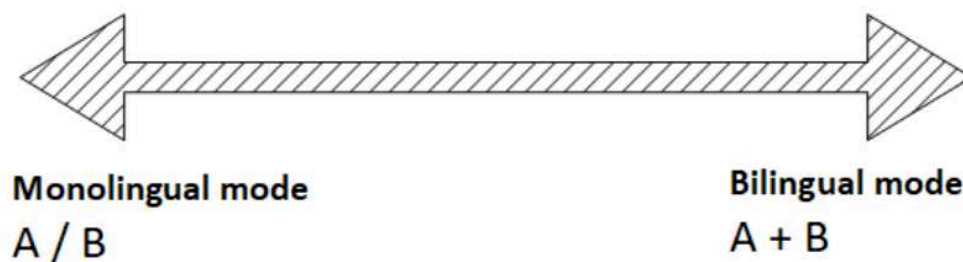


Figure 23. The bilingual speech modes' continuum.

In the monolingual mode, bilinguals interact with monolingual speakers in one of their languages (A or B), using only one of them and deactivating, as much as possible, the other unused language. Nevertheless, a residual minimal activation of the deactivated language always exists: it appears in the form of interferences.

In contrast, in the bilingual mode, bilinguals communicate with other bilingual speakers who share the same two languages, mixing them spontaneously (A+B). The main characteristic of this speech mode is that the interlocutors adopt, unconsciously, a base language and then they mix the other language when needed. Thus, the two languages are always activated at the same time. The choice of this base language depends on various linguistic and psychosocial factors: sex, age, economic and social status,

communicative context and situation, topic, the speakers' level of fluency and so on. It can change more than once during the communicative act, too.

However, the decision of the speech mode that must be used is not easy nor predictable (Deprez 1994): it is a complex mechanism, linked to several factors in interaction (the interlocutors, the communicative situation, the topic and the function of the interaction) which operates in a rapid and subconscious manner. Errors in the evaluation can occur, too: sometimes the bilingual evaluates his/her interlocutor as a monolingual speaker and during the communication he/she realizes that he/she can speak and understand his/her two languages. So, he/she can switch to a more bilingual mode and use the two idioms. Inversely, it can happen that a bilingual interlocutor cannot or doesn't want to use one of the two languages, turning the communication to a more monolingual mode. It depends on changes coming from external factors, too.

2.1.3.2 Interferences, code-switching and borrowings

As we evoked in the monolingual mode, interference can be the sign of the unused language activation in a monolingual speech mode. Grosjean (Grosjean 1989) defines interference as "those deviations from the language being spoken (base language) due to the involuntary influence of the other "deactivated" language". They can be static or dynamic and occur in written and spoken language as well as at all grammatical levels (syntax, phonology, lexicon, semantics). For the French researcher, static interferences are those corresponding to a systematic permanent influence of one language to the other (for example the pronunciation with a foreign accent or giving a wrong meaning to a word constantly used), while dynamic interferences are random accidental intrusions, like the wrong accent given to a word following the phonetic rules of the other language and have not a huge impact on communication.

In the bilingual speech mode, bilinguals often mix the two languages. This operation can have two distinct forms: code-switching and borrowing.

In the case of code-switching, the speaker totally switches from one language to the other for a word, a phrase or a sentence. Several researchers (Treffers-Daller 1998; Sankoff and Poplack 1988; Bentahila and Davies 1983) studied the phenomenon of code-switching to understand its functioning and communicative strategies, since it shows the parallel simultaneous activation of the language systems and a real fluid discourse from a behavioural point of view. When this code alteration occurs, there is a break, a cut during the passage from one language to the other, even though the mechanism is fluent and totally natural, without any pauses. Bilinguals can practice code-switching for various purposes: first, because some concepts are better expressed in one language than in another, or one word lacks a reliable translation; secondly, because the topic of communication, since some arguments are mastered in only one of the two bilingual languages. Third, for social reasons: bilinguals can indirectly inform the interlocutor that he/she belongs to a specific group or, inversely, aims to distance himself/herself from a group. Lastly, code-switching can be used to report words directly in the language of the direct speech.

The second strategy to mix languages is borrowing: bilinguals literally borrow a word or an expression from the language not being spoken, adapting its phonology and morphology into the base language. Thus, borrowings are characterized by a formal and semantic integration, whereas code-switching is marked by juxtaposition. As Grosjean (Grosjean 1989) remarks, it is important to distinguish individual spontaneous borrowings from stable, linguistically recognised borrowings. This latter type includes all the foreign words being part of the vocabulary of a language, those regularly used by monolinguals, too. Spontaneous borrowings are frequent, but only a few of them become part of the language lexicon of an idiom, even though all languages in the world have words coming from regional and foreign languages.

All these kinds of interferences must be distinguished by intra-linguistic variations, like simplifications, hypercorrections and overgeneralizations, caused by an insufficient

linguistic level in one of the two languages. In fact, the interference frequency depends on the bilingual fluency (less interferences are linked to more fluency) and his/her emotional state (the more he/she is stressed or tired, the more it would be likely that interferences occur).

Lastly, the direction of the interferences is determined by language dominance: the more dominant language system influences the less strong ones. If the bilingual person is almost equally fluent in the two languages, interferences can be bidirectional and change during the bilingual lifetime.

2.1.3.3 Language readjustment and linguistic attrition

The individual first language is not always the dominant language: another additional language can become dominant in certain conditions. Moreover, bilingualism is not stable, and bilinguals can shift from one language to another, for example after the acquisition of a new foreign language which leads to the forgetting, partial or total, of the previous one. Fluency levels can change, too. In any case, the bilingual, as he/she is a communicator by nature (Grosjean 1989), will always have the adequate communicative and linguistic skills needed by the environment, modifying and adapting his/her competence.

The language configuration of bilinguals can be reorganized during the bilingual's lifetime, moving from periods of stable bilingualism to periods of readjustment. During language readjustment, the fields of use of the dominant language will increase in quantity and fluency quality, whereas the fields of use of the weaker language will decrease in number. Thus, linguistic competences in the dominant language will be stronger and more developed, since it is daily used; inversely, linguistic skills of the other language will be negatively influenced, even though it is the first language.

At the end of the process of readjustment, the bilingual individual will have acquired new essential communicative needs. But in what kind of interaction are the two languages

during readjustment? How does the speaker use the two languages, together or separately, during this period of change to avoid a lack of communicative competence? Researchers are still trying to answer these questions, putting their attention more on global communicative skills than on formal abilities in only one language.

Considering that even a first language can be restructured when in contact with another language, it can happen that one language is no longer used or is forgotten. This is the case of linguistic attrition, defined as the lack of someone's one language. It is the consequence of two languages' constant interaction which leads to a total deactivation or a simple inhibition. During language attrition the fields of communication and use decrease and the other language interferes more frequently through interferences and hesitations in the verbal act. The result is a new organization of the two subsystems, unconsciously made by the bilingual because some situations are no longer accessible in one of the two languages (Sorace 2005; Schmid and Köpke 2007; Schmid et al. 2004).

Consequently, attrition is a phenomenon directly linked to memory functioning, emotional factors and the storage of linguistic skills. During attrition, the cognitive demands are really high since the strong dominance of L2, which must be inhibited in order to preserve the L1, results in important difficulties in L1 production (Köpke and Schmid 2011). However, at the present time we don't have any assurance that L1 is more inclined than L2 to attrition, or conversely (Paradis 2007). The only certitude is that the more the brain is plastic the more it is apt to replace an ancient knowledge with a new one: brain plasticity, or the neuroanatomical modifications in the brain under the effect of environment, is in fact strongly associated with learning. We will analyse this factor in the last parts of this chapter.

To conclude, situational, environmental and necessity changes oblige the bilingual to constantly restructure his/her language competence, walking on the continuum between monolingualism and bilingualism. This shifting doesn't have any consequences on his/her basic language competence, which remains always intact.

2.2 Different types of bilinguals

As we already said, bilinguals are different from each other. Thus, several typologies and categorisations reflecting the multidimensional character are possible; the most common distinctions made in research are:

- Balanced vs. Unbalanced bilinguals: for balanced bilinguals the linguistic competence in the two languages is almost equal, even though the fluency level is not high or fully developed. It is not the case for unbalanced bilinguals.
- Early vs. Late bilinguals: the distinction is made based on the age of exposure to languages. Early bilinguals have acquired the two languages in early childhood, whereas late bilinguals have become bilinguals after childhood. An additional distinction is made between *simultaneous* bilinguals and *successive* or *sequential* bilinguals: the formers have been exposed to the two languages since they were toddlers (Houwer 2009); the latter have been exposed to only one language in a first time (their mother tongue) and then to a second language, for example at the nursery or elementary school (Thompson 2000). The upcoming section of this chapter is reserved to the detailed explication of all these typologies.
- Compound vs. Coordinate vs. Subordinate bilinguals: this distinction, made by Uriel Weinreich (Weinreich 1953), corresponds to the linguistic code organization in the bilinguals' memory. In compound bilinguals two linguistic codes are stored in the same conceptual unit; in coordinate bilinguals each linguistic code is stored in two distinct conceptual units; in subordinate bilinguals the linguistic codes are organized in one conceptual unit, but the access is made by the L1, and it depends on the different learning contexts.
- Additive vs. Subtractive bilinguals: this distinction is proposed by W. E. Lambert (Lambert 1973) and concerns the linguistic dynamic in the bilingual speaker. Additive bilinguals are those who can increase their L2 competence without losing their L1 competence; in contrast, in subtractive bilinguals the new competence in the L2 negatively impacts the L1.

- Folk vs. Popular bilinguals: this social distinction made by J. A. Fishman (Fishman 1977) differentiates speakers' groups living in a society where their L1 is a minoritarian language with a low social status from groups speaking the dominant language of the society they live in, plus another language.

All these different dimensions are frequently interrelated. However, early and late bilingualism is the most studied and used discrimination when we talk about bilingualism and second language acquisition. We will focus on these two typologies in the next section.

2.2.1 Classification: early, late, simultaneous and sequential bilinguals

Everybody can become bilingual at any age. Several studies have shown that children who have grown with two languages since birth are a real minority all over the world (Pearson and Fernández 1994). There are several factors, psychological, linguistic, social and educational, that can influence the way we learn one or more languages.

We can acquire two languages at home, at school, in the street, in a special community, at the nursery school or later, at the high school, in adult language classes or at work. Thus, learning is shaped by formal and informal interactions and language planning: second language classes are a clear example of formal language acquisition, since they are usually based on direct linguistic instructions, even though naturalistic settings developing communicative competence in a less formal way are even possible.

2.2.1.1 Early simultaneous acquisition

The belief that acquiring two languages from birth is detrimental for the child's language development has been wrongly claimed for many years. On the contrary, several researchers, like De Houwer (Houwer 2009), Meisel (Meisel 2004) and Genesee (Genesee 2003), have demonstrated that babies are biologically ready to acquire and store different linguistic systems from birth and that bilingualism has beneficial cognitive, communicative and social effects.

Deuchar and Quay (Deuchar and Quay 2001), and Genesee (Genesee 2001, 2003) affirmed that babies are capable to differentiate between the two languages and to store the two languages receiving the input and producing the output. Thus, early bilingualism follows the same steps as the monolingual acquisition in the linguistic and communicative development, and in cognitive and social functions. This mechanism is displayed by the lexical development: the total number of words of bilingual children is the same of the corresponding monolingual, considering the two vocabularies of the two languages, but the vocabulary size of each language in bilingual children can be smaller than that of monolingual children. On the other hand, bilingual children are faster than monolingual in the acquisition of new words and concepts since they usually pay attention to people referring to the same thing in different languages (Houwer 2009).

How bilingual children store two linguistic systems from birth and how they develop the two languages has been largely debated. For the first question, two main theories have been proposed: the unitary language hypothesis (Nicoladis 1998; Nicoladis and Genesee 1997) argued that young bilingual children develop one integrated system, whereas the separate language hypothesis (Genesee 2001) affirmed that the languages of bilingual children are represented in two distinct systems, developing autonomously and interdependently.

In addition, three theories have been proposed about early simultaneous bilingual development:

1. Children develop first one language system which is divided in two sub-systems with time, one for each language (Volterra and Taeschner 1978);

2. Children have two different and separated language systems since the beginning of their language learning (De Houwer 2015);
3. Children have two different systems but one of them may influence the other, normally the dominant language on the less strong (Döpke 2000; Grosjean 2001).

The third hypothesis is the more convincing one since researchers have shown that it is rare that the two languages develop at the same time with the same speed. The influence of the dominant language on the other through interference is one of the empirical effects of this interconnection. Moreover, this unequal relation produces a more rapid development of certain structures in one language compared to the other: this effect is also caused by the intrinsic nature of some linguistic rules and constructions that are easier to learn or less complex in one language than in the other (Grosjean 2015).

Most of the psycholinguists working on bilingualism agree on the special ability of the simultaneous bilingual speakers to build their grammars and vocabularies, assigning to each language its proper distinctive attributes. He/she succeeds in this operation leaning on prosodical, structural and phonetic cues of each language and evaluating in depth the context of communication and the interlocutors.

Different routes can bring to early bilingualism: parents, education and the community can play an important role. Moreover, since bilingualism is not a static category, the distribution of the two languages can vary on time, as well as their use and experiences.

Four kinds of early childhood bilingualism are reported here (Baker 2011).

In the first approach, called *One person – one language* (Grammont 1902), each parent uses a different language to his/her child and they tend to speak one language to each other (the same as one of the two or even a third different language). This theory focuses on the importance of separate languages since the beginning, avoiding confusion and code-mixing in the bilingual child. The linguist George Saunders (Saunders 1982, pg. 49) added that this approach “ensures that the children have regular exposure to and have to

make use of each language. This is particularly important for the minority language, which has little outside support.”

This method is popularly adopted by several families and is considered the most successful strategy for bilingual language acquisition (Ronjat 1913; Escudé and Pierre 2010; De Houwer 1998). However, some critics (Houwer 2007) have been addressed to this method arguing that it doesn't take into account the importance of the linguistic community influence, like school, multiculturalism, extended family, social media. Okita (2002) adds that the parental input required for the child to acquire the two languages is persistent and consistent, so it risks being less natural. If parents over-control all their productions, the young learner will be exposed to an unnatural, in some cases artificial, input: parental language input pattern is, in fact, the main factor for successfully bilingual children, even though it is a difficult process requiring hard work from parents.

The second type of early bilingual development is when the language spoken at home is different from the language spoken outside. In this case, the child acquires a language at home since birth, used by both parents, and another language outside, in the street, in the social environment, at school, and so on. It is not rare that one of the parents is “obliged” to speak in his/her L2 at home. This approach is usually adopted when the language used at home is a minoritarian language in order to preserve it from the external linguistic environment.

The third approach focuses on code-switching and code-mixing: the parents speak both languages to the child and the two strategies to mix languages are accepted at home. In this case, the child learns to naturally code-switch and code-mix with other bilinguals but not with monolinguals or in linguistic situations where a separation of the two codes is expected (e.g., school).

The last kind of method is when a delay in the exposure to the second language is produced. The child's first language is often a minoritarian language (but there are exceptions) learnt in an exclusive way from birth to the first three or four years, when he/she starts going to school. In this way, parents are sure that the L1 is well developed and strongly grounded in the linguistic stockage of their child before the second language appears.

To sum up, several aspects influence the early simultaneous bilingual development during his/her personal growth; for this reason, Nicoladis and Genesee (1997) argued that child's language choices and code-mixing frequency are unconscious and depend on various factors: language education, social linguistic norms, emotions, different social contexts of exposure, attitudes of parents and peers to the two languages and to mixing languages, language proficiency and metalinguistic abilities.

2.2.1.2 Late sequential acquisition

Sequential bilingualism refers to situations where a person (young or adult) acquires a first language and then a second language in which they become proficient. Normally the L1 is the dominant one and is acquired at home and learners get in contact with the L2 at school or in the social external environment where they live. Thus, they have a well-structured language before acquiring a new language and they can use their first language to facilitate the L2 learning.

Researchers don't agree about the age marking the boundaries between early and late bilingualism; a whole section of chapter three will focus on the question of critical age.

The sequential acquisition may be formal or informal, in the street, at school, with friends, in formal or informal classes and language laboratories. The reasons why a person decides to learn an additional language can be societal or individual: acquiring a second language is not just about reaching a new grammar, a new vocabulary and new phonetic rules. It is rather a social event, often linked to a social group (Bourdieu 1977); in this process, the social and linguistic dimensions are strictly connected: the speaker wants to be understood, but also aims to be respected and believed.

At the same time, societal and political dynamics (Bourdieu et al. 1991) can encourage people to the acquisition of a second language, even in adulthood: for economic and commercial reasons, for assimilation and educational reasons (e.g., when the child speaks

only the minoritarian language of his/her family), to develop interactions between countries and access to a country's information and culture (Cook 2002). On the other hand, a person can decide to learn a second language later in life for a great deal of individual reasons: the most common are cultural awareness, cognitive development, affective and personal goals, professional needs and to feel integrated in a social group. Moreover, as demonstrated by Garrett (2010), Cenoz (2009), Baker (1992), Dörnyei (2001), and others, attitudes and motivation play a central role in success or failure of a second language learning. Integrative motivations, or the wish to join and to identify with a language group, are accompanied or not by instrumental motivations, or useful purposes. These two kinds of motivations are changeable in time (Pavlenko 2002) and can be mixed (Lukmani 1972): a person's motives may be a combination of the two without a real distinction.

When a child or an adult starts learning a new language, different factors come into play. Fillmore (Fillmore 1991a, 1991b) has identified three main components in interaction in children becoming bilinguals without a conscious and formal learning: the context of the two languages' interaction, the learners themselves, since they know they are in a learning situation, and the speakers of the language learnt who will help learners in the L2 acquisition.

The American linguist adds to these factors different social processes in action during learning: learners pay attention to the linguistic and communicative strategies of their interlocutors, guessing and formulating hypotheses on the topic of discussion. At the same time, they encourage their interlocutors to be sensitive to their needs, adjusting their linguistic production in order to be understood. Thus, learners try to join a group making the effort to understand the verbal exchanges, giving the impression they master their codes and counting on their peers and friends to improve their skills.

Late learners build their competences on linguistic processes, too. They use their interlocutors to obtain information about the L2 functioning and usage, putting their attention on what it is said and how it is said through repeating linguistic aspects used in a certain context. They use their first language, too. The L2 provides the linguistic

knowledge to find the corresponding equivalents in the new one: in observing the context of communication and in employing their cognitive competences, they discover the linguistic units and rules of the new language, while exploring new connections and associations through cognitive learning strategies, like analysis and interpretation.

This whole mechanism allows learners to pass through different interlanguages, as Selinker (1972) defined the learner's linguistic system composed by some features of the L1 and some intra-linguistic traits, like overgeneralizations, simplifications and overcorrections, of the L2. The L1 dominance in successive bilinguals usually produces interference during code-mixing, especially at the beginning of the second language acquisition, in order to help speakers to communicate (Deprez 1994). This L1 interference will decrease with time and fluency.

To conclude, it is necessary to evoke the importance of the education programs in late learning; it exists in two kinds of schools: schools discouraging bilingualism and schools promoting the usage of different languages. The formers involve, most of the time, minoritarian languages: children speaking niche or minor languages are not encouraged to develop the school language preserving their first language; on the contrary, they will be led to pass from a monolingualism in their first language to another monolingualism in the dominant, majoritarian language. On the other side, schools encouraging bilingualism are based on the principle that children speaking the country's official language learn another foreign language and children whose L1 is a foreign language learn the official language of the country. Different school programs are sometimes implemented, like multilingual classes, immersive learning and linguistic exchanges.

2.2.2 How bilinguals differ from monolinguals

Bilingualism is a large domain where different dimensions are in contact and constantly communicate, like our representation of bilinguals, the cognitive and linguistic effects produced, as well as the diversity between bilingual individuals.

As we explained in the previous section, bilingualism has been seen as detrimental for child development for a long time, at least during the 19th and the 20th centuries, the so-called “black years” (Tabouret-Keller 2011). Today things have changed and knowing several languages is almost a daily necessity, even though there still exist teachers, psychologists or speech therapists who are convinced that identity crisis, personal confusion and speech troubles can be caused by bilingualism (Deprez 1994).

A great amount of studies on bilingualism (Saer 1923; Macnamara 1967; Peal and Lambert 1962) produced distinct results when bilingual children were compared to the corresponding monolinguals: several domains were investigated, like the intelligence level, some mathematical skills or the metalinguistic thinking. If some results were negative, like those coming from the studies of Saer (Saer 1923) and Saer, Smith and Hughes (Saer, Smith, and Hughes 1924) where bilingual students had disadvantages in thinking compared to monolinguals, most others showed a global positive effect of bilingualism. Bilingual children had, in fact, a better mental flexibility, a major linguistic creativity, were more sensitive to semantic relations and had a better consciousness of the words' double composition of form and meaning. Sandra Ben-Zeev (Ben-Zeev 1977) and Ianco-Worrall (Ianco-Worrall 1972) reported that the connection between the form and the meaning is less fixed in bilinguals, who are aware of the arbitrariness of the sign.

A distinguishing feature of bilinguals is the Complementarity Principle, introduced by Grosjean (Grosjean 1997): bilinguals learn and use their two, or more, languages in different situations, with different people and for distinct purposes. Thus, the acquisition and treatment of the bilingual two languages depend on topics, communicative contexts and intentions.

It can happen that certain domains or activities are exclusive to only one language or that they are shared between the two. The domains and topics repartition can change during

the bilingual lifetime. The Complementarity Principle is supported by other researchers, like Claude Hagège (Hagège 1996), who explains that sometimes one language can be preferred for some specific fields, generating a language functionality specialization. This principle is based on language use, but it has an impact on linguistic knowledge, too. In fact, if one language is used only in a few contexts or activities, with a restricted number of interlocutors, it will probably be less developed than the other stronger language. Thus, the vocabulary size (narrower than the other one), the discursive and pragmatic abilities risk to be afflicted, both in oral and written contexts.

The Complementarity Principle is also confirmed by the difference in size and internal organization between the monolingual and bilingual vocabulary, since bilingual children are exposed to different words in different languages for the same mental concept. The bilingual vocabulary planning is set on domains and linguistic systems: some fields are covered by the two languages, whereas others by just only one language, giving rise to specific dictionaries. In contrast, the monolingual lexicon is constructed on features and concepts of only one linguistic code: this distinction is maintained during the whole individuals' lifetime (Bialystok and Craik 2010).

Another distinction in the comparison between monolinguals and bilinguals' outcomes concerns metalinguistic activities: bilinguals seem to be more efficient in tasks where they must meditate on language and with activities of linguistic processing and intentional planification. In their experiments, Craik and Bialystok (Bialystok and Craik 2010) analyse the bilingual advantage using tasks engaging selective attention and inhibitory control where bilinguals performed better than monolinguals. The authors explain this effect through the daily bilingual needs of controlling and using several languages, including code alternance, borrowings, changing communicative contexts. They are more practical and familiar with these competences than monolinguals, thus more efficient.

2.2.2.1 Languages in interaction

In bilingualism the nature, qualitative and quantitative, of the linguistic input has a central role. It is, in fact, responsible for the child's vocabulary development and the correlation between the exposure to a language and the size of the initial individual lexicon is strong. Pearson and his colleagues (Pearson et al. 1997) attested that the number of words in each language of a bilingual is directly proportional: their studies demonstrated that the comprehension vocabulary of each language was comparable to the one of the corresponding monolinguals, whereas the production vocabulary was smaller if the input was reduced to less than 20% than monolinguals.

Several studies have also been made to attest that the lexical development and the grammatical emergence occur in the same way in monolinguals and bilinguals (Goodman and Bates 1997). The hypothesis of the Critical Mass proposed by Bates and Marchmann (Marchman and Bates 1994), which states that learning words corresponds to learning their semantic, morphological and syntactic features, has also been validated for bilingual children. Moreover, the theory that lexical knowledge facilitates the emergence of grammar is true for bilinguals, too.

The acquisition of a new language is quite independent from the degree of performance in the other, since young bilinguals can differentiate their two languages very quickly in the linguistic development (De Houwer 2005). Nonetheless, as we had already seen, some interference can occur in the form of code-mixing, doublets or borrowings. Children often use words of their L1 when speaking in their L2 because they don't know the corresponding word in the L2 or because this word doesn't exist in that language. This mechanism is controlled by structural and functional constraints, and it is a real linguistic resource to use communicative strategies.

In the bilingual environment the individual speaker exploits all his/her adapting strategies to optimize the cognitive complexity of the bilingual input processing based on the task, the available languages and the communicative context. Thus, the idea that his/her languages are constantly active at different degrees and in persistent interaction has found an empirical application in studies about language dominance, typological distance and tasks processing.

The theory that language is a dynamic system where linguistic categories can arise through the interaction between the learner and the linguistic properties of the environment, proposed by Elman in 1990, represents the base for studies (Li and Sporleder 2010) analysing the ways in which language representations are organized in a whole that changes during development. The bilingual lexical organization is strictly marked by the interaction between the two languages: some effects of the organization of one language to the other have, in fact, been identified. In particular, in simultaneous bilingualism two vocabularies are differentiated with the development of distinct lexical representations, while in sequential bilingualism the lexical space belonging to the L1 is restructured in order to assess an independent representation of the L2, but if the second language is introduced too late in the bilingual lifetime, this independence risks to be compromise. In this case, the L2 learning is mediated by the connections already fixed in the L1. In contrast, in simultaneous bilinguals the two vocabularies (L1 and L2) compete with each other from the very beginning of language acquisition.

All these assumptions show that, in learning, the initial dynamics of language interaction have an impact on the subsequent linguistic development. Consequences of this impact can be positive or negative, depending on learning conditions.

Another issue that needs to be discussed concerns the several cases of multilingualism where a huge number of people actually live all over the world. For several years it was assumed that bilingualism hindered the acquisition of another additional language; on the contrary, the most actual widespread theory is that bilingualism favours a third language learning (Cenoz and Genesee 1998; Cenoz 2003). In fact, all the cognitive, social and linguistic advantages of bilingualism, like enhanced learning strategies and linguistic strategies, cognitive flexibility, metalinguistic awareness and self-confidence, have a positive impact on the acquisition of a third language. Hoffmann (Hoffmann and Stavans 2007) underlines the complexity of the activation/deactivation dynamics in trilingual speakers where two dimensions are central for the analysis of competences: the role of dominant linguistic codes in the three-languages interactions and the languages typological proximity.

2.2.3 Methodological challenges

Cognitive and linguistic studies on bilingualism and bilingual subjects are more complex than the corresponding ones conducted with monolinguals. Since its beginnings, the research on bilingualism has created surveys to be submitted to speakers in order to analyse their competences, their linguistic history, as well as their own perception of their double linguistic skills.

Behavioural and neurophysiological studies with bilinguals often lack experimental models and control groups; and empirical data are often ambiguous or inconsistent. In his work, De Groot (Groot 2011) highlights the importance of adapting methodology to each distinct field of study, even before the presentations of results and models. In the definition of a bilingual experiments three main factors must be controlled:

- a. Participants
- b. Experimental paradigms
- c. Models.

Participants obey the Grosjean's Complementarity Principle (Grosjean 1998, 2016), so they are not equally fluent in the two languages, always having one dominant or stronger language (Schlyter 1993). This is considered a bilingual intrinsic variability. When we compare monolinguals and bilinguals, we have to keep in mind that, at the heart of bilingual development, there also exists the inter-variability and that sometimes the corresponding monolingual controls are not adequate. Thus, several empirical data and information risk to fail.

The definition of the experimental paradigm is crucial: as Grosjean (Grosjean 1998) affirms it is necessary to adapt the methodological strategies to the phenomenon studied; if not, it becomes impossible to analyse the results distinguishing between the bias coming from the study purposes and the techniques used.

Lastly, the field of research on bilingualism is quite recent and insufficient. For several years psycholinguistic studies have been conducted exclusively on monolinguals, which caused an actual lack of bilingual models (Grosjean 1998). As Klein (Klein 2015) underlines,

nowadays we still lack interdisciplinary works on bilinguals that notably focus on the distance (in terms of fields of use) between the two languages.

2.3 First and second language learning

Determining the degree of linguistic performance of bilinguals is a complex challenge since the conceptualisation of these performances depends on theories characterizing language acquisition. For this reason, the field of second language acquisition has been strongly influenced by theories of first language acquisition.

In this section, we will present the three main approaches proposed to explain L1 learning functioning and how they have been applied to second language acquisition, as well as the models of L2 learning developed. In the last part, we will briefly analyse the main factors of language learning, namely the importance of the quality and quantity of the input, the question of the linguistic dominance and the language typology.

2.3.1 Theories on language acquisition

Bilingualism is a complex phenomenon, not easy to define. Moreover, another parallel field of study has increasingly developed during the late seventy years: the Second Language Acquisition (SLA). Through theoretical hypothesis and empirical research, it analyses the ways in which second languages are acquired, bringing new information on language learning, too.

The thin boundaries between bilingualism and second language learning do not allow us to completely separate their respective theories: in fact, some SLA models can also be

applied to bilingual processing, like the question of the critical age. For this reason, in this section we will firstly present different approaches proposed for the First Language Acquisition; then some models describing the Second Language Acquisition and processing, applicable to second language learners and to bilingual speakers.

2.3.1.1 First Language Acquisition

In the field of studies on language acquisition the main question source of debate is: do children acquire their mother tongue by means of linguistic structures already existing in their brain, or do they acquire the L1 through their general cognitive abilities?

We can distinguish three main theories, even though other approaches including different features have been proposed: the universalist theory, the cognitive-functionalist theory, and the sociocultural theory.

The universalist postulate is based on Chomsky's works (Chomsky 1965, 1981; Chomsky et al. 1981) and his theory of Universal Grammar. The hypothesis, supported by Pinker (Pinker 1987, 1995) and Fodor (Fodor 1983), is that the rules of the grammatical organization of language are too complex to be directly acquired or discovered by young children. Despite poor and, sometimes, incorrect input, the acquisition is rapid, and the grammar is perfect. Thus, this grammar is innate and is the same for all humans, who develop their linguistic abilities in the same way.

For universalists, all languages share the same structures, composed by principles and parameters (Chomsky 1981), and the innate grammar allows children to develop a generative ability producing complex output, made of constructions and phrases never heard before. The general cognitive structures don't impact the linguistic ability, which is completely independent and self-modulated.

On the opposite side, we find the cognitive-functional theory which gives importance to the relation between the linguistic development and the cognitive system, that becomes one of the main constituents of language activity. This approach, supported by several authors like Bates and MacWhinney (Bates and MacWhinney 1987), Lakoff (Lakoff 1987), Langacker (Langacker 1987), Plunkett and Strömquist (Plunkett, Strömquist, and Slobin 1992), Slobin (Slobin 1992), Tomasello, (Tomasello 1995, Tomasello 2000, Tomasello 2000, Tomasello 2003, Tomasello 2003); , Bybee (Bybee 2006, 2008, 2010), Morgenstern (Morgenstern and Sekali 2009) and others, confirms the possibility to learn grammar despite of its complexity. The functionalist theory is based on use: the linguistic knowledge of speakers can't be defined in terms of an innate grammar, rather than as a set of linguistic experiences varying in function of the statements processed. In this type of language acquisition, all the language components (phonology, semantics, pragmatics and vocabulary) work in interaction: grammar and lexicon can't, for example, be treated separately since a specific lexical unit is often linked to a specific grammatical structure (Bybee 2006).

From a cognitive point of view, language ability is not isolated, but it is integrated to the general cognitive and socio-cognitive system (Tomasello 2003; Lohmann and Tomasello 2003): language processing and acquisition are organized by the general inductive mechanisms of learning. Memory, perception and attention match with pragmatic components like intentions, reactions and intonations (MacWhinney 1987), giving to the speaker all the general acquisitional tools to correctly communicate.

As Allen (Allen 2007, p. 254) states "linguistic structures can only be understood and explained with reference to the semantic and communicative functions of language, whose primary function is to be a vehicle for social interaction among human beings".

The functionalist theory has also been the base of theoretical approaches in L2 acquisition: authors supporting this position (Green 1998; McLaughlin 1987; De Groot and Froll 1997) focused their attention especially on the organization of the two vocabularies in the learner's memory, as well as to his/her abilities of cognitive control, of automatization of control processing and on the abilities to keep or change the focus of attention.

The last approach is the sociocultural theory proposed by Vygotsky (Vygotsky and Cole 1978) which points on two main factors: the environment and the extra-linguistic context. Human development, and so language acquisition, are processes immersed in a social context which gives children the values and the cognitive, communicative and social strategies to interact with the others.

For him, learners use their language mostly for communicative purposes with their interlocutors: this interpersonal interactive speech can eventually be directed to the self, acquiring an intrapersonal function. From this point of view, social learning precedes any kind of development and is necessary to construct a general shared set of linguistic and psychological attitudes.

In the field of second language acquisition, this theory explores the social dimension of language, as well as the bilinguals' abilities to use adequate strategies in a given communicative context, matching with the interlocutors' features. Thus, the notion of variation is the heart of the sociolinguistic processes and analysis (McKay and Hornberger 1996; Preston 1993).

2.3.1.2 Second Language Acquisition

The theories proposed to explain the functioning of first language acquisition have been used and adapted to the study of second language acquisition, too.

Authors focused on different aspects proposing theories of a linguistic, socio-psychological and pedagogic nature trying to describe the main language features of language learning in interactive models. In this section we propose an overview of some theoretical ideas which took into consideration the complexity of language acquisition as well as its variety (different learners, different purposes, different environments) and which had practical applications in teaching strategies.

One of the main models is the Ellis' framework (Ellis 1985, 2015) which is constructed on the distinction of three main developmental components: the sequence in second language learning, the order in which a language is learnt and the rate of development of the second language. For Ellis, there exists a natural, invariant sequence of development in the stages of a L2 learning which doesn't depend on the type of linguistic system nor on the kind of learning (formal, informal). This sequence of acquisition is universal: from a simple lexicon to basic syntax, moving from simple sentences to more complex statements.

Secondly, the order of learning is different from the sequence of development: it can be different from person to person, and it refers to specific features of language. Finally, the rate of development and the level of proficiency achieved are deeply connected. In fact, the variation in the speed of a second language acquisition may vary from speaker to speaker, as well as the final level of proficiency.

In Ellis' theory an important place is occupied by situational factors, learning strategies, personality, personal attitudes and motivations which all affect the rate of development and the level of final proficiency, but don't influence the order nor the sequence of development. The learner's first language is an additional factor that does not influence the sequence of development, but it can have an impact on the order, the rate of development, as well as on the level of proficiency achieved.

These three main developmental components are at the heart of five factors which govern the acquisition in second language learning, constantly working in a strong correlation. Linguistic input, situational factors, individual learner differences, learner processes and second language output are interconnected in the processing of the L2 acquisition (Ellis 1985, 2015).

Moreover, Ellis gives a central role to instruction in language learning, participating in the controversy about the best instructional approach facilitating second language acquisition: the traditional method based on form and grammatical structures is opposed to a more modern approach, where linguistic properties are presented in context during activities centered on communication (Ellis et al. 2005; Ellis 2005, 2005). Thus, he proposed eleven principles representing the most relevant generalizations at the basis of

language teaching. In these principles, he highlights the importance of formulaic expressions in a rule-based competence development, the distinction between semantic and pragmatic meaning, the learner's focus on form during language acquisition (Hulstijn and Schmidt 1994; Schmidt 1995), the combination of implicit and explicit knowledge to succeed in L2 learning, the definition of instruction on the learner's built-in syllabus, the extended quality and quantity of L2 input, the creation of opportunities for output, social interactions and feedback, as well as the consideration of individual differences, the subjective aspects on learning a second language and the evaluation of proficiency on free and controlled productions.

Through these theoretical principles, Ellis (Ellis 1993, 2002, 2004, 2005) tried to formulate a computational model showing the relationship between language acquisition and language use, offering a sort of guide for the SLA.

The second theory we aim to present is the socio-psychological model of Lambert (Lambert 1973). In this framework, the fundamental factor is the social environment, combining individual features and societal elements in a set of relationships.

For Lambert, at the base of a second language acquisition there are the personal attitudes and motivations of the speaker, which are considered two of the main factors of success to become bilingual. Bilingual proficiency is then connected to self-identity which, in turn, gives rise to alternative outcomes: additive or subtractive bilingualism. Positive self is generally related to additive bilingualism, as well as the lack of pressure to acquire the second language which won't replace the first language; in contrast, negative self and a social pressure of learning a second language, which will substitute the first language, is likely related to subtractive bilingualism.

The last theoretical configuration we evoke in this section is the socio-educational model of Gardner (Gardner, Smythe, and Clément 1979; Gardner 1983; Gardner and Lalonde 1985), organized in four stages.

The first one is the learner's social and cultural background, who can be influenced by the values, the beliefs and the culture of the country where he/she is living. The second step is occupied by individual differences made of four main variables: integrativeness,

motivation, attitude and anxiety, and language aptitude. For Gardner, in fact, the degree of a learner's intelligence, motivation, aptitude for language learning and anxiety affects the outcomes in L2. The last two stages concern respectively the language acquisition contexts (formal or informal) and the outcomes, which can be of two types: linguistic (the bilingual proficiency achieved) and non-linguistic (changes in attitudes, cultural values, beliefs and self-concept). Since learning a second language and becoming bilinguals may change attitudes, and so affect motivation and anxiety, the model of Gardner is cyclical, not static.

These models are a kind of summary of all the theories proposed between the 19th and the 20th centuries to explain second language processing, highlighting the dominant factors of influence in bilingual development. However, they are not exhaustive and each of them has limitations which we can't treat in detail in this chapter.

2.3.1.3 Models of Second Language Learning

Since becoming bilingual often involves second language acquisition, various theories have been developed to describe individual and contextual conditions for success in L2 acquisition (Fillmore's Socio-linguistic Cognitive Theory (Fillmore 1991), Chomsky's Universal Hypothesis (Chomsky 1965), Hatch's Discourse Theory (Hatch 1979), Lamendella's Neurofunctional Theory (Lamendella 1979).

In this section we will analyse three of the main models of second language learning: the Schumann's Acculturation Model proposed in 1978 (Schumann 1976, 1986), the Giles and Byrne's Accommodation Theory (Giles and Byrne 1982; Beebe and Giles 1984) and the Krashen's Monitor Model (Krashen 1977, 1981, 1982). Each of these models is based on specific linguistic and social features and has been criticized for different reasons.

The Acculturation Model proposed by Schumann in 1978 is centered on the idea that language is an important component of culture, so the relationship between the learner's

linguistic community and the second language community have a crucial role in L2 learning success. In fact, in the acquisition of a new language, learners have to adapt themselves to a new culture. Schumann portrays various social and psychological factors facilitating the acquisition, like the social equality between the two linguistic groups, which share values, beliefs and social facilities; the congruence and similarity between the two cultural groups; the positive attitudes and expectations of each other; personal confusion and feeling of stress and anxiety; culture shock; the degree of inhibition or motivation.

All these variables provide the amount of contact with the target language, made of individual, social and external factors. In fact, when psychological and social distances are large, the learner can fail to progress in second language learning, whereas when psychological and social distances are positive, the learner can progress relatively effortlessly.

Moreover, Schumann identifies three main language functions: communicative, integrative and expressive. Language allows the transmission of information, aids the affiliation of a social group and exhibits the individual feelings and personality. In second language learning, these functions are still observed but sometimes the learner may not achieve the expressive use of the second language or may not be integrated in the new social group.

The second model is Giles and Byrne's theory (Giles and Byrne 1982) which explains second language learning through the relationships between ingroup and outgroup. The social proximity or distance between the ingroup (the language learner's social group) and the outgroup (the target language social group) are in a constant dynamic and negotiated exchange which can vary in time.

For Giles and Byrne, the learner must have specific features to succeed in L2 acquisition: having a weak social and ethnic group identification; not making comparisons of the social status between the groups, highlighting negative differences; perceiving the boundaries between his/her group and the outgroup as open and flexible.

The Accommodation Model, like the Acculturation Theory, is essentially a socio-psychological model rather than a cognitive model explaining the processing and the mechanisms of second language learning. The third model, the Krashen's Monitor Model, has become the most widely cited theory in second language acquisition since it has allowed a practical adaptation in education.

The Monitor Model proposed by Krashen (Krashen 1977, 1981, 1982) is fundamentally constructed on five hypotheses which represent the variables of second language learning.

The first one is the acquisition learning hypothesis where an important distinction between acquisition and learning is made: acquisition is a subconscious process resulting from natural and informal contexts of communication without any reflexion on language itself; contrarily, learning is a conscious process and occurs in formal, driven and artificial contexts where language properties are taught. This distinction is essentially made on the conscious thinking about rules (second language learning) and the unconscious linguistic feelings in language usage (second language acquisition).

The second hypothesis is linked to the linguistic input: if the learner is exposed to a kind of $n+1$ input, or a little more complex stimulus than his/her current level, he/she will understand it and will naturally acquire the features connected to the input itself. In fact, input is comprehensible through the help of the situational context.

The third hypothesis is the monitor theory. It is conceived as an editing device operating before the linguistic output, or after the performance in the form of a correcting device. This monitor modifies utterances and allows the production of communicative correct productions; thus, it can occur only when the learner has enough time and when he/she knows the appropriate speech rules.

The fourth one is the natural order hypothesis for which the grammatical structures are acquired in a fixed, predictable order, without distinctions between children and adults and independently the language learnt. A standard order occurs any time a learner

engages in natural communication, without worrying about individual and external variations.

The last hypothesis is the affective filter: Krashen suggests that some affective factors, like motivation, self-confidence, anxiety and linguistic attitude, influence the rate of second language learning development. Learners with stronger filters can block the second language learning input, and so don't succeed in becoming bilinguals.

2.3.2 Lexico-semantic processing in bilinguals

Since the representations of words are connected to the representations of meanings, in bilinguals this association is not stable, but it varies with L2 development. Several researchers have proposed models describing this development, thus the functioning of the bilingual lexico-semantic processing.

One of these models considers the differences between groups of bilinguals: in 1984 Potter, So, Von Eckardt and Feldman identified two bilingual lexico-semantic organizations, depending on the stage of learning. The first one, called word-association model, is applied to L2 learners at the beginning of learning and assumes that, in a translation pair, a direct connection between L1 and L2 words is established and between the L1 words and its meaning. On the other hand, the concept-mediation model, applied to proficient bilinguals, affirms that, in a translation pair, L1 and L2 words are directly connected to a shared meaning representation, without any connection between L1 and L2 words. This pattern implies that direct connections between L2 words and meanings gradually develop with L2 proficiency and linguistic experience.

Starting from this view, other models have been elaborated, like the Revised Hierarchical Model proposed by Kroll and her colleagues (Kroll and Stewart 1994; Kroll et al. 2002). This model (Figure 24) is a sort of integration of the two Potter's models (Potter et al. 1984), with the difference that it assumes direct links between L1 and L2 words; however, the hypothesis that both words are connected to a shared meaning representational

system remains. Thus, in the Revised Hierarchical Model we find two unidirectional connections: one from L2 to L1 and another from L1 to L2, the first one being stronger than the second. Moreover, the two connections from L1 and L2 words to the shared meaning system are different in strength (the one from L2 words is weaker than the one from L1 words) since they depend on the language use. The assumption is, in fact, that the first language is more frequently used in a larger number of domains compared to the second language: the connection strength determines the speed of activation allowing the connection between words and meaning. With growth in L2 use and proficiency, the direct connections between L2 words and the L1/L2 shared meanings become stronger, thus direct, without engaging L1 words.

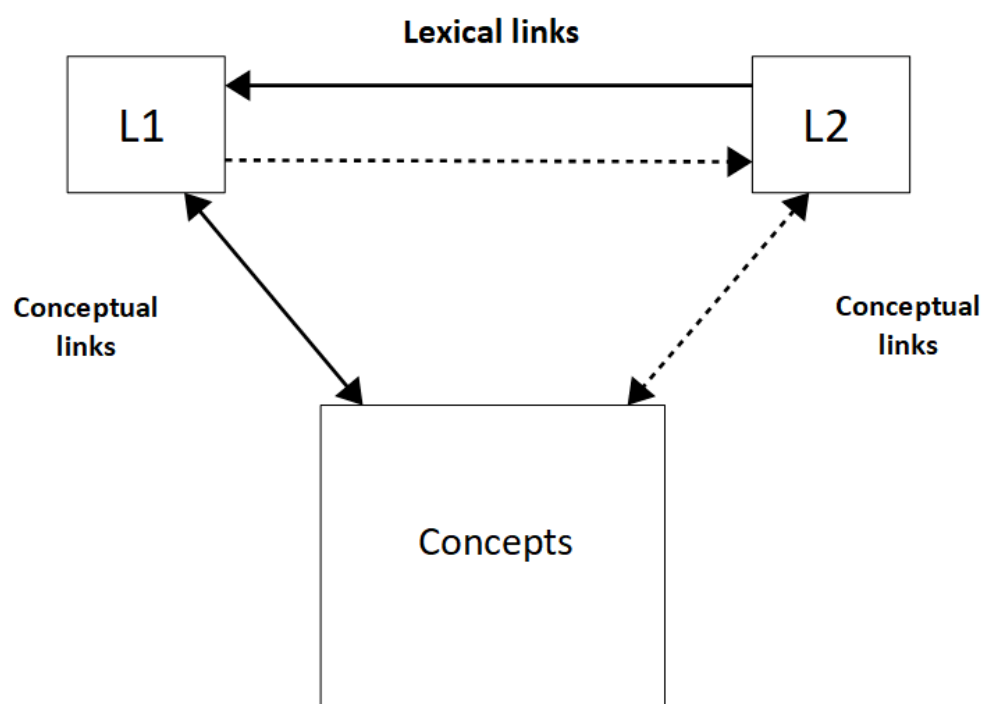


Figure 24: The Revised Hierarchical Model (Kroll and Stewart 1994).

Additional models, like the Sense Model (Finkbeiner et al. 2004) or the Developmental Model of Jiang (Jiang 2000) and the Modified Hierarchical Model by Pavlenko in 2009 (Schwieter 2011; Pavlenko 2009), have put their attention specifically on the evolving content and the semantic components of the bilingual lexico-semantic representations.

One of the most complex of them is the Shared Distributed Asymmetrical Model designed by Dong, Gui and Mac Whinney (2005). The authors started from the assumption that the meaning of a word is a collection of various elementary specific meanings; thus, the exact set of these meanings associated with a word and the connections' strength between the word and this set of meanings changes over time, with the increase in L2 proficiency. At the early stage of learning, the L2 words adopt the meaning of the corresponding L1 words and the strength of the connections between the L2 words and the meanings set are weaker than those between the L1 words and the meaning units.

With the increase in L2 proficiency the connections between L2 words and the common meanings become stronger, and a set of L2-specific meaning elements gradually develops. Therefore, the Shared Distributed Asymmetrical Model is clearly centered on the theory that bilinguals word meanings change over time and may differ from individual to individual.

2.3.3 Variables of learning: input, learning strategies, dominance and language typology

The field of second language learning studies has shown that various variables interact during the language acquisition processing (De Groot 1995; De Groot 2010). The more dominant are context of acquisition, cultural background, level of L2 proficiency, type of linguistic input and of learning strategy, frequency of L2 usage, language dominance and typological diversity of languages in contact.

In this section we will put the attention mostly on four of them, notably the effects of bilingual input, the implicit and explicit language learning, the notion of dominance and the comparison between languages from a typological point of view.

2.3.3.1 The linguistic input

Providing a suitable linguistic input for the developmental stage of the second language learning is one of the main prerogatives to allow learners to achieve bilingual competences.

Qualitatively, the second language learner and the native speaker work together to succeed in efficient communication: they use shared cognitive and linguistic strategies to make conversation meaningful and appropriate to the context. For example, in the negotiation of meaning and to allow mutual comprehension, they can choose topics of discussion in which the two are proficient, or the native speaker can speak slowly, stressing key words and repeating some sentences if needed. On the other hand, the learner can give signals, verbal and non-verbal, to mark lack of understanding or a need to change the linguistic register or topic of conversation.

However, from a quantitative point of view, the input received by bilingual children, in each of his/her languages, is two times less consistent than the corresponding monolingual children. The most realistic case of unbalanced input corresponds to 30% - 40% of input in one of the two languages. Thus, it is not surprising if sometimes bilingualism doesn't succeed in an optimal way (Houwer 2009). Accordingly, bilingual competence develops most of the time based on the input unbalance, whereas bilingual competence does not. For this reason, in a bilingual study, it is suitable to estimate the input proportion on each learner's language.

2.3.3.2 The Language Dominance

The notion of language dominance is inherent to bilingualism. In fact, even in simultaneous bilinguals there is always a "stronger", dominant language which takes part in the evaluation of the child's perceptual skills. During the bilingual lifetime, the pattern of the dominant language can change: the linguistic code which prevailed in a time can then become the weaker one (Romaine 1995).

Several authors have proposed different measures of language dominance, each of them focusing on specific factors of variability: for example, MacWhinney (MacWhinney and Chang 2000) proposed the *Mean Length of Utterance* (MLU), or the evaluation made on the average length of sentences; Schlyter (Schlyter 1993) kept constant the differentiation between strong and weak languages; Genesee and his colleagues (Genesee, Nicoladis, and Paradis 1995) highlighted the importance of the longest sentence (*upper bound*) produced by the child during an experimental session; and Jisa (Jisa 2000) proposed to evaluate bilinguals on the basis of their fluency, the quantity of code-mixing and the lexical occurrences.

2.3.3.3 Linguistic typology differences

In bilingualism, the coexistence of two languages in one speaker requires a functional organization in systems based on the linguistic components (phonology, semantics, syntax and vocabulary): this organization can be influenced by the similarity (or not) of the two languages.

Crosslinguistic studies in L1 on language comparison showed that a comparative approach is essential to define the universal and language specific constraints during the language acquisition processing (Slobin 1985; Slobin 2013). In bilingual acquisition, crosslinguistic research has been spread to the contrastive analysis of a specific linguistic level (e.g., words, sentences, narrative strategies) or to a specific domain (e.g., space, time, colours) or to couples of languages, typologically similar, where various kinds of transfer are expected.

In 1996, Slobin introduced the “thinking for speaking” hypothesis: our mother tongue gives us some definite lexical and grammatical options which set up the situation coding in a specific way. These preferences develop during the child's first language acquisition and are actually the object of several studies on bilingualism.

We will analyse this theory more in detail in the next section of this chapter.

2.3.4 The question of the critical age

Young learners seem to be more proficient than adults in learning a second language: the beginning of the L2 age of acquisition varies from an individual to another and can represent an important variable in the learning process. For this reason, the relationship between the age of L2 acquisition and success in gaining language proficiency has become one of the main themes of debate in linguistics.

One argument is the theory called “The Critical Period Hypothesis” which states that the lower the age at which a second language is learnt, the greater the proficiency in that language lasts in time. Thus, for this hypothesis the human being is provided with some particular dispositions in language learning (L1 and L2) which are disponsible only during a specific period of his life, corresponding to the neurophysiological development of the brain. After this period, some kinds of learning would not be possible anymore.

Following this viewpoint, language is caught, not taught for children, who acquire more easily and successfully a new idiom.

On the opposite side, there is the hypothesis that older children and adults learn a new language faster and more efficiently since they have major and completely developed intellectual skills and superior cognitive competences.

2.3.4.1 The Critical Period Hypothesis in details

To better understand “The Critical Period Hypothesis” we need to go back to its origins: this notion has appeared for the first time in 1920 (Spemann 1938) in the field of experimental embryology and in 1930 in developmental neurobiology to analyse how neurons realize good connections during the nervous system development. Thus, at its beginnings, this notion was focused on short phenomena starting and finishing rapidly, whose effects are permanent. In 1960 the theory of critical period was extended to studies in experimental ethology with Lorenz in 1967 (Benes 2004) and the notion of *imprinting*, limited in time.

Almost at the same time, Lenneberg (Lenneberg 1967) conducted some studies in neurolinguistics on the biological foundations of language: his work popularized the “The Critical Period Hypothesis”. Assuming the presence of a critical period in a given learning process allows the fixation of temporal limits: its onset and its offset, two variables not simply defined with complex cognitive functions. Moreover, this viewpoint asserts that all kinds of learning released during the critical period must be identical for all individuals and controlled by endogenous factors, like maturation, whereas exogenous factors, like environment, don't impact the learning process.

In contrast, learning realized beyond the critical age is sensitive to individual and environmental variations, and, in some cases, it becomes very difficult, even impossible.

First language acquisition has been one of the main fields of study in linguistics to test the existence and the conditions of the critical age. In a broadest sense, the age of acquisition refers to the age at which a skill or ability is acquired; in L1 processing, it refers to a stimulus feature of linguistic items: for example, the difference in processing early learned words and late learned words (Carroll and White 1973; Gilhooly and Watson 1981). Since the age of words acquisition affects the accuracy and the speed of word access (Morrison, Chappell, and Ellis 1997; Ellis and Morrison 1998; Lewis 1999; (Meschyan and Hernandez 2002; Meschyan and Hernandez 2002), early learned words typically elicit faster response times than late learned words in lexical and cognitive tasks.

Several researchers, like Malson (Malson 1964), worked on wild children who, abandoned at birth, lived in nature with animals, completely deprived of linguistic input. Results have been discordant: in some cases, children were supposed to not be able to acquire language even after having been immersed in human society, whereas in other cases, where the isolation ended before puberty, children can recover normal language competences.

A key factor of “The Critical Period Hypothesis” is the age at the end of this period. Since the debate is still open and unsolved, in this chapter we won't go in details, just evoking the fact that the ages proposed vary from one author to the other: for example, 5 years for Krashen (Krashen 1973), 6 years for Pinker (Pinker 1995), 12 years for Lenneberg (Lenneberg 1967) and 15 years for Johnson (Johnson and Newport 1989).

Moreover, following Newport's principle "less is more" (Johnson and Newport 1991), young children are better at acquiring languages due to more restricted cognitive capacities, too. In fact, at the beginning of their life, children have a restricted set of simple grammatical units, and then, with the linguistic and cognitive development, they acquire more complex units; in contrast, adults start with the analysis of the input complexity and struggle to extract regularities. Newport's studies have shown that young children can acquire regular patterns even though the input is inconsistent.

From a neural point of view, several researches have demonstrated the same advantage in babies comparing to adults: for Kuhl and his colleagues (Kuhl et al. 2005) for example, the baby exposition to a second language cause a decline in the non-native phonetic contrasts linked to the progress made in the native language, which needs a consistent neural engagement interfering with the processing in the non-native language.

Another last central principle of this theory is the negative correlation between the age of acquisition and the proficiency in L2. Johnson and Newport wanted to demonstrate that the ability to acquire a new language decrease with age and the presence of a discontinuity in learning, due to the cerebral maturation period's closure. For the authors, the results they obtained all supported the predictions of the critical period hypothesis, but when Hakuna, Bialystok and Wiley (Hakuta, Bialystok, and Wiley 2003) tried to duplicate Johnson and Newport results, their data didn't confirm the "The Critical Period Hypothesis" in L2 acquisition. In fact, they highlighted that other factors, like the typological proximity of languages, the educational level and the decrease of cognitive abilities and working memory skills, have a role in second language learning as decisive as the age of acquisition.

Starting from these results, different critics have been moved to the hypothesis of critical age: one of the more severe have been those of Singleton (Singleton 2005) who said "It is not a hypothesis either; it is at best an extremely vague promissory note".

2.3.4.2 Critics to The Critical Period Hypothesis

The critics addressed to the notion of critical period insisted on the fact that differences in the learning process could involve general mechanisms of cognition, not specific to language, like the working memory, as well as structural differences between languages which could explain some limits in achieving a native competence.

Different research has shown that even early immersed bilinguals don't always obtain native skills in their second language and that, at the same time, some later learners can reach a high level of performance, similar to natives. In fact, McDonald's studies (McDonald 2006) on the role of working memory and Friederici's studies (Friederici, Steinhauer, and Pfeifer 2002) on the neural mechanisms of L2 learners disproved, in two different domains, the theory of the existence of a specific language mechanism efficient only for a limited period of time.

Works conducted by Singleton (Singleton 1989), Marinova-Todd et al. (Marinova-Todd, Marshall, and Snow 2000), Cenoz (Cenoz 2009) and Singleton and Ryan (Singleton and Ryan 2004) all analysed different aspects linked to the critical age. First, younger learners are not more or less efficient or successful in second language learning than adults since many factors impact the process of acquisition. One of these is the length of exposure, or the number of years during which the learner has been in contact with the second language, in a natural or formal environment. Length of exposure is central in L2 success, and it is a focal discussed point in the field of education: children who begin to learn a second language in the elementary school and continue throughout all their education, are likely more proficient than children who start later in their schooling. For this reason, late learners can become highly proficient, attaining a native-like competence, particularly when they are strongly motivated or have excellent opportunities of extensive immersion.

Secondly, children learning a second language in childhood tend to achieve higher proficiency levels than those beginning after childhood because of social contexts in which language is acquired and maintained. Motivation, opportunities and other individual psychological factors can facilitate the acquisition, too. Thus, the differences between early and late learners are connected to the situation of learning rather than to the capacity to learn (Marinova-Todd, Marshall, and Snow 2000). Thus, it seems clear that

there are no differences that directly lie to ages of language learning, since young and adult speakers share a similar developmental order and sequence.

Thirdly, in a formal classroom language learning tends to be quicker for older learners for the first time compared to young learners. This factor can be explained with the global cognitive and linguistic development of late learners which is globally completed; moreover, they can exploit all their linguistic resources, structures and cognitive strategies in their L1 to learn the L2, adapting them to the new linguistic system. However, this procedure can generate some kinds of transfer from one language to another: differentiation, forward transfer, backward transfer or amalgamation (Kilborn and Ito 1989).

All these assumptions show that there is not an empirical definable end point in learning and that adults and young learners have the same qualitative characteristics; differences in the outcomes are just linked to environmental effects (Hakuta 2001). Marinova-Todd et al. (Marinova-Todd, Marshall, and Snow 2000) added that, even though we can't admit the existence of a critical period for language learning, some advantageous periods can exist: for example, early childhood and elementary schooling in second language.

“Age does influence language learning, but primarily because it is associated with social, psychological, educational and other factors that can affect L2 proficiency, not because of any critical period that limits the possibility of language learning by adults”. Marinova-Todd et al. (Marinova-Todd, Marshall, and Snow 2000, p. 28).

2.4 Bilingualism and cognition

The effects of bilingualism on cognitive processing have questioned a huge group of researchers since the last century. However, the research line on how mastering two or

more languages influences the mental mechanisms of language, language use and structures involved, as well as the comparison between monolingual and bilingual linguistic abilities and outcomes (De Groot 2011), provided different answers over the years.

The first studies have typically been focused on performance deficiencies of bilingual speakers compared to monolinguals; in recent years, an enormous increase in the amount and diversity of research have examined individuals at all stages of their lifespan, showing cognitive advantages coming from the bilingual experience. These studies used various behavioural and neurophysiological methods, employing experimental paradigms more accurate and appropriate to bilingual subjects and the corresponding monolinguals which were based on the new insights on bilingual attentional control.

In fact, the two bilingual languages are jointly activated even when only one of them is used (Marian, Blumenfeld, and Kaushanskaya 2007; Hernandez, Bates, and Avila 1996). This double constant activation requires an adaptive bilingual mind which has to select and avoid interference from the unwanted language. The importance of the selective attention processes and the inhibitory control has become a central point in the analysis of bilingual effects on cognition, which seem to spread throughout life, even in old age. Bialystok and his colleagues (Bialystok et al. 2009) obtained some positive results for the correlation between bilingualism and cognitive decline: in the treatment of the linguistic and non-linguistic information, bilinguals seem to slow down the normal aging process, as well as the insurgence of cognitive pathologies.

As several interdisciplinary studies discovered, the bilingual experience requires a huge cognitive cost, notably in language production, but it seems to be beneficial for non-linguistic abilities and tasks.

2.4.1 The *Thinking for speaking* hypothesis

In the attempts to determine the functioning and mental structures underlying cognition, perception, reasoning and worldview, in linguistic and extra-linguistic contexts, a new perspective is proposed by Dan Isaac Slobin in 1996.

Since each language provides a set of grammatical options to encode experience in verbal utterances, and since each utterance is influenced by the experiences made by the locutor, the verbal action is constructed in the process of speaking. Thus, experiences are filtered through the language system used.

The grammaticised meanings of the language's speaker determine a specific schematization of a concept, necessary for verbal expressions, on whose basis are constructed utterances. Therefore, the same concept can be lexicalised in only one word in a language and in more than one word, or even in sentences, in another language.

Following a typological approach, Slobin explains that language comparisons can help the understanding of the connection between language and cognition: they can, in fact, lead to the hypothesis that each language imposes some defined constraints which partially structure the cognition organization. This assumption joins the Sapir-Whorf linguistic relativity position, proposing a new version of this theory based on the strong correlation between two entities: thinking and speaking.

Slobin's theory *Thinking for speaking* (Slobin 1985, 1987, 1992, 1996, 2003), in fact, assumes that a special kind of thinking exists: it is strictly linked to language, notably in the process of linguistic production, or the thinking carried out during the speaking process.

“In my own formulation: the expression of experience in linguistic terms constitutes thinking for speaking – a special form of thought that is mobilized for communication.” (Slobin 1996, p. 76).

Slobin focuses the attention on the verbal event: when we speak, a special activity of thinking occurs, using a combination of grammaticalized concepts and mental contents

accessible for use. Thus, during the construction of utterances, the speaker selects the characteristics of the object or the event which better correspond to the event conceptualization, and which are ready to be linguistically encoded in the language used.

For this reason, each speaker acquires particular ways of thinking for speaking specific to his/her native language: his/her mother tongue trains him/her to pay attention to specific features of objects, experiences and events when talking about them. When children acquire two or more languages, they also learn different kinds of verbalizing events through the linguistic categories of each language, affecting their thought during the verbal production.

“The language or languages that we learn in childhood are not neutral coding systems of an objective reality. Rather, each one is a subjective orientation to the world of human experience, and this orientation affects the ways in which we think while we are speaking.” (Slobin 1996, p. 91).

2.4.2 Bilingual disadvantages

From 1920 to approximately the 1960s, the dominant belief in the cognitive linguistic field of study was that bilingualism had a negative effect on mental skills. The anxiety that mastering two languages may have a detrimental effect on an individual's thinking abilities and linguistic performances was a widespread viewpoint. Thus, the aim of the early studies on the negative effects of bilingualism was to confirm, through experimental methods, that learning a second language impaired the first language skills (the more the L2 increases, the more the L1 decreases) and that speaking two languages has efficiency costs. Bilinguals would have less place to store other learning domains compared to monolinguals, who, in contrast, have maximal storage space for any kind of information, because of only one language system reservoir.

One of the most explored domains for demonstrating the bilingual deficiency is the vocabulary size: various authors, like Pearson, Fernandez, Oller (Pearson, Fernández, and Oller 1993), agree on the assessment that the bilingual lexicon of each language is smaller than the corresponding monolingual ones. They assume that the vocabulary size is on average lower in bilingual children than monolingual children, but the number of concepts is the same. Moreover, in some studies (Bialystok et al. 2010) the bilingual global vocabulary (first and second language combined) appears to be more extensive than those of monolingual participants. In fact, through their constant and daily use of the two language systems, they acquired more linguistic units in the two languages, even though sometimes they lack the mutual translation (Bialystok, Craik, and Luk 2012).

All these results showed that determining the level and the size of the bilingual vocabulary is a complex task requiring experimental paradigms constructed on the bilingual specific features: tests and experiments are too often projected on monolingual reference standards with high risks of bias.

Another aspect connected to bilingual disadvantages pointed out by some researchers (Francis 2005) is the lexical access. Following their assumptions, bilinguals have shared connected semantic representations with separate representations at the lexical unit level, in each of the two languages. Thus, their prediction is that bilinguals have a different treatment of lexical processing compared to monolinguals. In contrast, they should have similar performances than monolinguals in conceptual processing tasks.

Gollan and his colleagues (Finkbeiner et al. 2004) actually demonstrated that, in a naming task, bilinguals named more slowly the images presented and were less accurate than the corresponding monolinguals. The authors tried to explain this result with the fact that bilinguals have a different experience in naming objects in each of his/her language, since he/she daily uses the two linguistic systems. Thus, they use their two languages, causing deficiencies in the lexical representations due to a lower frequency of use.

Other authors, like Ivanova and Costa (Ivanova and Costa 2008), explained this bilingual disadvantage as the effect of the interference between the two languages: the words of the unwanted language are still active during the task and come in competition during the selection of the representations in the language required.

These studies represent only a narrow set of the various research made in the bilingual domain to demonstrate the negative effects on cognition. Systematic disadvantages in the bilingual abilities have regularly been highlighted in a variety of tasks, lexical decision, verbal fluency, lexical access and semantic identification. At the same time, interlanguage interactions have been analysed, as well. MacWhinney (MacWhinney 2005) and Morford, Wilkinson, Villwock, Pinar and Kroll (Morford et al. 2011) have, for example, conducted some studies to prove that interactions between languages, whether typologically similar or dissimilar, exist at each level of linguistic processing (phonology, syntax, grammar, lexicon) and last all the bilingual life long, whatever the linguistic automaticity degree achieved.

To conclude this section on bilingual disadvantages, it is worth considering some relevant aspects which can impact the obtained or expected results. Starting from the assumption that bilingualism is not a categorical variable (Luk and Bialystok 2013), the quality of the study is fundamental: to evaluate its validity, research on bilingualism must be constructed on individual's specific language groups and on tasks where the cognitive outcome is likely to be impacted by bilingualism. In fact, not all tasks require linguistic and cognitive processing linked to bilingualism: studies need to empirically demonstrate a real relationship between the task chosen and the bilingual information treatment. Thus, to evaluate the hypothesis that bilingualism correlates with cognitive functions, an approach constructed on theoretical motivations is needed.

These methodological weaknesses, in addition to those about the overgeneralized population samples, the choice of the language tests, the types of classification and

statistical analysis, as well as the lack of consideration of the linguistic and cultural environment, have been the early bilingual studies' main limitations.

In fact, modern and recent studies attest that bilinguals don't have any potential disadvantage in cognitive tasks compared to monolinguals. There still exists some research suggesting differences between monolinguals and bilinguals, in favour of monolingual better performances in language-specific processing. We cite notably Gollan and his colleagues' work on semantic fluency (Gollan, Montoya, and Werner 2002) and Kaushanskaya and Marian work on picture naming (Kaushanskaya and Marian 2007): in both cases, bilinguals seem to be slower. This effect could be possibly explained with the fact that bilinguals use some words of each language less often than monolinguals (Michael and Gollan 2005), that interferences can occur from one language to the other (Costa, Santesteban, and Caño 2005) and even with the fact that, in a semantic task, bilinguals need more time to choose the correct word in their double language lexicon (Bialystok, Craik, and Luk 2008).

However, none of these studies demonstrates that bilinguals have less developed cognitive skills, have mental overloads or process inefficiently. In fact, as Gollan et al. (Gollan et al. 2008) suggested, bilinguals use by definition their two languages less often than monolinguals in their daily life; thus, it is not surprising that the bilingual lexical access is weaker and slower than monolinguals.

2.4.3 Research factors on bilingualism and cognition

As we evoked in the previous section, several studies have been conducted to prove that the bilingual advantage effects are inconsistent (Costa et al. 2009); Hilchey and Klein 2011; Paap and Greenberg 2013; Hilchey, Saint-Aubin, and Klein 2015). The first study demonstrating that bilingualism has no negative effects on cognitive functioning, rather

it conveys benefits in verbal and non-verbal intellectual abilities, has been that of Pearl and Lambert in 1962.

Before starting a detailed analysis of the theoretical and empirical principles of the bilingual advantage hypothesis, presenting some studies showing cognitive benefits of bilinguals (Bialystok et al. 2004); Bialystok, Craik, and Luk 2008; Costa, Hernández, and Sebastián-Gallés 2008; Pelham and Abrams 2014), it is worth underling some questions involving publication and new trends of the bilingual advantage investigation.

Bruin, Treccani and Della Sala (Bruin, Treccani, and Sala 2014) provided evidence for a publication bias in favour of positive results proving the existence of a bilingual advantage. For the authors, the huge number of publications on positive results compared to those on negative or null effects represents a considerable explanation of the bilingual advantage hypothesis' success in research. Analysing several abstracts of the conferences on the bilingualism and executive control debate between 1999 and 2012, they identified the studies which have been finally published. The discrepancy between the studies supporting the bilingual advantage theory and those challenging it was evident: despite any difference in the experimental paradigms, the statistical data or the sample size, the latter were published the least and were not all selected.

Another important point in the actual debate about the bilingual advantage, is the changing questions put at the origin of the studies. In fact, rather than questioning about the presence or absence of bilingual benefits, in the last years, researchers have focused their attention on the locus and on the moment of the bilingual advantage. In other words, recent studies use various linguistic and cognitive tasks, like the Stroop test, the ANT test, the Simon test and the Flanker test, to examine the uniqueness of bilingual linguistic processing. Moreover, their research has opened to discriminations within heterogeneous bilingual groups: the distinctions between bilinguals with different features (for example, the proficiency level, the age of acquisition, children vs. adult participants, languages' typological similarity) are the new focal center of interest in the field of bilingualism.

2.5 The bilingual advantage

If we admit that experience can define the human brain structure and cognitive skills, we need to consider language as one of the most integrative and powerful experience in human life: it, in fact, has an active role on all our activities, not only for verbal and non-verbal communication, but also to conceptualize reality. Moreover, the language use engages most of the major brain regions (posterior, temporal, frontal and parietal), supporting the hypothesis that experiences connected to language don't involve just language-specific processes, but more general domains (Bialystok 2017).

In recent years, researchers of various fields have increasingly analysed the effects of bilingualism, and multilingualism, on language processing and general cognitive abilities. The way in which bilinguals master the two language systems and the differences in their outcomes compared to the corresponding monolingual groups has become a central argument of the debate on the bilingual advantage. With the expression "bilingual advantage" we refer to the idea that bilingualism has benefits for cognitive abilities: this notion extends the advantages of using and mastering more than one language to more general non-linguistic cognitive control tasks.

This hypothesis considers the theory of a constant joint activation of the two languages, which share an integrated bilingual lexicon without any selective access. The key point comes from the evidence that both languages in the bilingual's lexical storage are always active, even though one of them is not required for the current task, like in completely monolingual communicative contexts (van Heuven, Dijkstra, and Grainger 1998; Martin et al. 2009). The parallel activation creates a competition for selection that must be controlled by the bilingual speaker: to resolve this linguistic competition, the bilingual must pay attention to the double language representations and the linguistic environment, selecting the correct target language and inhibiting the non-target one or, eventually, he/she must be able to rapidly switch from one system to the other. In the absence of such effective control, there would be a constant risk of intrusion of the non-target language. Thus, bilinguals engage more cognitive demands on a control system than do monolinguals, leading to enhanced executive control processes (Bialystok 2001),

which, in turn, result in better performances, thus less interference, in various tasks, namely those constructed on conflict resolution.

In fact, to evaluate the bilingual cognitive advantage different experimental methods have been identified: the most frequently used are Sorting tasks (Bialystok 1999), ANT tasks (Carlson and Meltzoff 2008; Costa, Hernández, and Sebastián-Gallés 2008), Simon tasks (Bialystok 2006; Bialystok et al. 2004), Flanker tasks (Costa, Hernández, and Sebastián-Gallés 2008; Costa et al. 2009), and Go/No-go tasks (Emmorey et al. 2008). Results showed that bilinguals are globally more efficient than monolinguals in tasks where the irrelevant information must be inhibited or where discordant information is presented, creating a cognitive conflict.

When we talk about general cognition, we refer to a set of processes involving inhibition, attention, selection, updating, task-switching and conflict monitoring. Since bilingualism requires the constant engagement of the whole executive control system, it may have an impact on other non-verbal cognitive processing with which the linguistic systems share some resources within a more general representational system. Some common processes, like executive functions or language inhibition, are shared too.

Therefore, the interaction between language and cognition is constant and complex (Kroll and Bialystok 2013), especially in cases where individuals need to master two or more linguistic systems. During the evolution of the hypothesis, the bilingual cognitive advantage theory put also the attention on the locus in which bilingualism confers cognitive control advantage (Della Sala and Grafman 2014). The debate is still open and competing viewpoints have emerged during the years: two of the most cited domains are, for example, the role in executive functions and the enhanced inhibition in conflict tasks. The constant competition for selection, within one language and between different languages, occurs simultaneously during comprehension and production of linguistic utterances (Marian and Spivey 2003; (Kroll, Bobb, and Wodniecka 2006). As a result, during this process, the interaction between the networks involved in language processing and those employed for general cognitive control (Coderre et al. 2016) becomes stronger

than in the monolingual linguistic-cognitive processes. This mechanism leads to an advantage in the cognitive control networks (Stocco et al. 2014).

However, several recent researches demonstrated that some results obtained in favour of the bilingual advantage have not always considered other variables that can impact the bilingual outcomes, including proficiency, the degree of interference of the L2 and the context of linguistic immersion (Coderre, Heuven, and Conklin 2013). Some additional crucial points in this debate have notably concerned the type of experimental tasks, information regarding monolingual and bilingual groups tested (Luk and Bialystok 2013), the contexts of learning and use of their two languages (Green and Abutalebi 2013) and the cognitive resources supposed to be impacted by bilingualism (Takahesu Tabori, Mech, and Atagi 2018).

For this reason, as we examined in the previous section of this chapter, some studies have been conducted to contrast the supposed bilingual advantages on control tasks, showing even the presence of a bilingual disadvantage in some activities (e.g., in lexical access tasks). The cognitive benefits of bilingualism, in fact, seem to be counterbalanced by the linguistic costs, which slow down the performances: this debate is finding its center in the notion of “bilingual paradox”, developed by Sorace (2011), that considers the bilinguals’ syntactic and pragmatic competences, not only the lexical ones, rethinking the idea of “bilingual linguistic disadvantages”.

2.5.1 Additional benefits of the bilingual experience

The interest of the bilingual effects has not been restricted to benefits in the executive processes of control, it has rather investigated other areas of cognitive processing, like metalinguistic skills, anticipatory abilities and aging cognitive decline.

2.5.1.1 Bilingual metalinguistic competences

Various studies have demonstrated that the bilingual experience seems to strengthen the metalinguistic abilities of bilingual children compared to their corresponding monolinguals (Bialystok 1988; Cummins 1978; Galambos and Goldin-Meadow 1990).

The metalinguistic activities concern the aptitude to thinking about language and to give a judgment on the different components of language, as well as on its modalities of expression and comprehension. Vygotsky (Vygotsky 1962) has been the first who suggested a possible effect of bilingualism on the sensibility to understand the arbitrary relation between a word's form and meaning. Different studies have been conducted to prove this hypothesis (Bialystok 1986; Campbell and Sais 1995; Galambos and Goldin-Meadow 1990; Moreno et al. 2010) in phonology, semantic and syntax.

“The child learns to see his language as one particular system among many, to view its phenomena under more general categories, and this leads to awareness of his linguistic operations”. (Vygotsky 1962, p. 110)

More recent studies (Siegal, Iozzi, and Surian 2009; Siegal et al. 2010) have also analysed the bilingual competences on pragmatics in order to evaluate whether bilingualism furnishes advantages in the comprehension of some pragmatic aspects of a verbal exchange. The purpose of their works was notably to establish whether bilingual children have some benefits in their skills to discriminate between answers more or less meaningful from a communicative point of view. The results showed that, although the vocabulary of bilingual children is less large in each of their languages than that of their monolingual counterpart, they develop, during the years, specific compensatory abilities. Thus, they learn to address their attentional resources on pragmatic aspects of the conversation more than monolingual children do, using the contextual information to construct the meaning of the communicative messages.

Therefore, all these studies on pragmatic and metalinguistic abilities have demonstrated that bilingual speakers have stronger skills to control their attention exclusively on relevant information when other significant information must be simultaneously ignored.

This advantage has been identified in bilingual children and bilingual adults, even though it doesn't always ensure better metalinguistic performances. Other variables (the diversity of experimental situations and tasks, the typological diversity or similarity of the languages tested or the degree of engagement of specific executive functions resources) can, in fact, play an important role in the benefits found.

2.5.1.2 Bilingual anticipatory skills

The bilingual advantage hypothesis has also been tested on the bilingual competences in anticipation. Bonifacci, Giombini, Bellocchi and Contento (Bonifacci et al. 2011) have supposed that bilingualism may have beneficial effects on anticipatory abilities in linguistic and cognitive tasks.

The human brain is constantly engaged in the production of predictions about future events (Kveraga, Ghuman, and Bar 2007): these predictions facilitate perception through the activation of relevant information, in order to correctly anticipate future actions. This process is constructed on global representations, made of properties related to the same specific experience, which create associations organized in memory (contextual frames). These frames are not activated only by the specific experience to which they are associated, but also in new situations: our brain tries constantly to find some analogies between the new unknown situation and those already stocked. Once the analogies are identified, it activates the associated representations making the prediction possible.

In social and communicative interactions, this process regularly occurs to allow mutual understanding through the anticipation, in grammatical and syntactic terms, of what our interlocutors are going to say. It operates in coordination with the other cognitive functions and is not restricted to language domains, but it involves different sensorial systems related to the human probabilistic reasoning using the available information, stocked in memory, to make predictions on future events (Kveraga, Ghuman, and Bar 2007).

In their study, Bonifacci and colleagues (Bonifacci et al. 2011) have observed that bilinguals are able to anticipate with more accuracy the elements in a sequence than monolinguals, even though any significant differences in the processing and memory speed have been recorded between the two groups. All these data highlight how bilingualism impacts, in a beneficial way, various specific cognitive mechanisms, revealing that anticipatory skills represent an innovative field of study to prove the bilingual cognitive advantage.

2.5.1.3 Bilingual aging and cognitive decline

Cognitive studies on bilingual adults have concerned elderly people, too. The amount of published works and theoretical models dedicated to changes in cognitive functions connected to aging has increased during the last twenty years (Lemaire and Bherer 2005). The effects of aging have mostly been examined in three domains: memory, problem solving and reasoning skills. Since in each of these cognitive activities only some processes are impacted by aging, whereas others remain intact, the detrimental effects of aging on cognitive performances can be explained by different possible factors: the reduction of the attentional resources (selective attention), decreased abilities of the working memory and global cognitive delaying during the information processing (Taconnat and Lemaire 2014).

Starting from studies conducted with healthy monolingual subjects analysing the variations in executive functions determined by aging, Bialystok and his colleagues (Bialystok et al. 2004) have tested younger and older adult monolinguals and bilinguals in the Simon task. Their results reported better performances of bilinguals than monolinguals and a greater disparity between older adults and young adults, the former having the slowest reaction times. Thus, the authors concluded that, because of the daily use of two language systems for several years, bilingualism improves different aspects of cognitive function even in adulthood and may represent a factor of protection against age-correlated cognitive decline.

As Stern theorized in 2002 (Stern 2002) with the concept known as *cognitive reserve*, cognitive decline with aging can be modulated by some kinds of experience. The cognitive reserve allows to preserve the normal cognitive functioning challenged by cognitive decline linked to aging, dementia or neurodegenerative pathologies. Several studies have demonstrated that different kinds of experiences, like educational level (Kramer et al. 2004; Wilson, Barnes, and Bennett 2006; Bennett, Bennett, and Allen 2003), aerobic exercise (Erickson et al. 2011; Colcombe et al. 2003), stimulating activities like music and video games (Ferreira et al. 2015; Wilson et al. 2002; Vemuri et al. 2012; Scarmeas et al. 2001; Bavelier and Davidson 2013; Karle, Watter, and Shedden 2010), have a beneficial impact on cognitive functions, especially in elderly subjects, provoking a less severe cognitive decline. Bilingualism is part of these experiences, contributing to the cognitive reserve.

To further analyse the contribution of bilingualism to the cognitive reserve, different studies have been conducted with adult unhealthy subjects affected by dementia, Alzheimer's disease and in post-stroke recovery. For bilingual patients affected by dementia and Alzheimer's disease, the majority of the results has attested they had better performance on cognitive measures than monolinguals (Bialystok, Craik, and Freedman 2007; Zahodne et al. 2014; Klein, Christie, and Parkvall 2016; Craik, Bialystok, and Freedman 2010; Bialystok et al. 2014; Wilson et al. 2015): it seems, in fact, that bilingualism postpones the age of emergence of these pathologies, but without avoiding the disease's onset.

The most cited study on the connection between bilingualism and stroke is that of Alladi and his colleagues (Alladi et al. 2016). The authors supposed that bilingualism could contribute to post-stroke recovery, without any expectation on its impact to the prevention or the delaying of the stroke occurrence. The results showed that various factors had a beneficial impact on cognitive recovery following stroke: the two more significant ones were age and bilingualism. The double rate of bilinguals compared to monolinguals presented, in fact, normal cognitive functions at the end of the therapy.

Therefore, all these data are in line with the hypothesis of an overall protective effect of bilingualism on cognitive functions and neurodegenerative diseases.

2.5.2 Neuroplasticity in bilinguals

One of the most important changes in recent cognitive neuroscience studies comes from the evidence of neural and cognitive neuroplasticity related to experience, as well as the effects of the environment on brain structures (Kroll and Bialystok 2013).

Since experience may be a means to modify our cognitive systems and brain structure, some kinds of experience impact our development: bilingualism is supposed to be one of them. The permanent exposition and use of two or more language systems seem to have structural and functional consequences that have been detected during the last decades: the effects of bilingualism on language processing and cognition in general require a stronger and more developed adult neuroplasticity, not identified in monolinguals.

This new field of study allowed the definition of new methodologies and multidimensional analysis, which are adjusted to the bilingual complex dynamic system: one of the new variables considered in more recent researches is the variation within the bilingual group, depending on their linguistic and non-linguistic experience (Luk and Bialystok 2013).

“Intellectually his experience with two language systems seems to have left him with a mental flexibility, a superiority in concept formation, and a more diversified set of mental abilities, in the sense that the patterns of abilities developed by bilinguals were more heterogeneous” (Peal and Lambert 1962, p. 20)

Thus, the use of two languages during an individual’s lifetime produces neurocognitive differences between monolinguals and bilinguals: to explain the modifications of brain and cognition connected to the bilingual experience, we need to consider the executive

function systems. We will analyse in detail the role of executive functions in bilingual speakers in the next section of this chapter, but some models proposing a definition of the executive functions processing seem important to be mentioned in this passage.

One of them is that of Baddeley (Baddeley et al. 1986) who proposed the model of working memory which included a central executive structure, moderating the functioning of domain-specific systems through attention.

Another model where a central role is played by attention is that of Engle and his colleagues (Shipstead, Harrison, and Engle 2015): the authors proposed the notion of working memory capacity, which is a combination of attention and working memory. The two factors interact to produce a complex cognitive system; the capacity they talk about is not a storage space but rather the duration to which resources rest available to control attention and to finalize the current task (Engle 2018; Engle and Kane 2004). The Engle's working memory capacity is, thus, consistent with the results showing the effects of plasticity found across the lifespan of bilingual subjects: the common process to data coming from infants, children and adults is attention.

However, even though experience influences both bilinguals' cognitive constructions and brain organization and functioning during their entire life, the relation between the bilingual experience and the consequent cognitive and brain modifications are quite complex. Various studies have, in fact, demonstrated that other variables may have a determinant role in the development of executive functions, non-verbal intelligence and decision-making skills: for example, spatial experience (Maguire et al. 2000), socio-economic factors (Noble, McCandliss, and Farah 2007; Mani et al. 2013), formal education and distance between languages (Costa, Hernández, and Sebastián-Gallés 2008; Yang, Hartanto, and Yang 2016; Antoniou et al. 2016; Abutalebi et al. 2015).

To conclude, we can assume that experience is a means to modify cognitive and brain systems, and the way in which we use language is one of the more powerful and deep ones. Bilingualism can, thus, change both our linguistic and cognitive strategies to process and master more than one language. Moreover, the multifunctionality of the human brain

requires the analysis of all the factors which can potentially define the human cognition. For this reason, to understand how bilingualism generates brain and cognitive changes, it is necessary to integrate empirical results obtained by researchers with locutors of all ages (from birth to old age) using experimental protocols evaluating all the bilingual phenomena from a behavioural and neurophysiological point of view.

The next section is, therefore, dedicated to the bilingual beneficial effects on inhibitory control and conflict monitoring, as well as to the role of selective attention and executive functions.

2.6 Executive functions and cognitive control in bilinguals

2.6.1 Bilingual enhanced Executive Functions

To avoid grammatical and lexical interference between languages, the bilingual speaker develops the ability to switch from one language to the other in order to maintain the conversation in the target language (Kroll, Bogulski, and McClain 2012; Misra et al. 2012; Kroll et al. 2012; Tokowicz and MacWhinney 2005). Cognitive control processes are crucially involved in this mechanism, reducing the effects of negative transfer and the incorrect use of the unwanted language in the bilingual communicative exchange, which would disrupt the understanding process (Bjorklund and Harnishfeger 1995; De Neys and Van Gelder 2009; MacWhinney 2005; Tokowicz and MacWhinney 2005). Thus, Executive Functions (EFs), or the set of cognitive processes such as inhibition, working memory, inhibitory control, selective attention and cognitive flexibility, are necessary for the behavioural cognitive control and have multiple functions.

Different models suggesting the main components of Executive Functions have been proposed. One of the most cited is that of Miyake, Friedman, Emerson, Witzki, Howerter and Wager (Miyake et al. 2000) which identifies three main distinct but correlated functions in executive control: inhibition, shifting and updating. Inhibition corresponds to the inhibition of the dominant response or distractors; the shifting process corresponds to the shifting of mental sets, linked to cognitive flexibility; the updating concerns the information in the working memory. From this viewpoint, inhibition and shifting are particularly involved in bilingualism since the former operates in the bilingual production, notably when the locutor has to decide how to switch from a language to the other, and the latter has been largely connected to the bilingual advantage theory for the stronger development of the inhibitory control (Houdé 1995; Craik and Bialystok 2005).

Therefore, the executive functions efficiency can be influenced by the constant use of multiple languages, with a simultaneous activation of the two languages at various levels (Green and Abutalebi 2013). Enhanced executive functions in bilinguals stem from the need to alternate between languages and to suppress one of them in parallel activated languages.

This cognitive enhancement has been theorized since the 19th century through different models related to cognitive inhibition and bilingual language processing. Green (1998) for example assumed that active inhibition, or the suppression of the irrelevant information and response, operates in bilinguals with the inhibition of the inappropriate language. In fact, various studies have reported an improvement in executive functions at all ages due to the use of multiple languages in bilinguals (Bialystok and DePape 2009; Costa, Hernández, and Sebastián-Gallés 2008; Diamond and Shreve 2010; Kroll et al. 2012), even in age groups that are normally characterized by decreased cognitive capacity, notably children and older people (Bialystok 2006; Diamond and Lee 2011; Zelazo, Craik, and Booth 2004; Bialystok 2007).

However, all the behavioural studies conducted on bilingualism as a means of enhancement of executive functions do not provide a uniform picture. While some researches obtained results attesting a clear bilingual advantage in tasks involving inhibitory control (Bialystok et al. 2004; Bialystok, Craik, and Luk 2008; Costa, Hernández,

and Sebastián-Gallés 2008; Linck, Hoshino, and Kroll 2008; Holmes, Gathercole, and Dunning 2010; Tao et al. 2011; Luk, Sa, and Bialystok 2011; Bialystok et al. 2004; Yang, Yang, and Lust 2011), others failed to show any advantage resulting from bilingualism (Carlson and Meltzoff 2008; Morton and Harper 2007; Costa et al. 2009). Heidlmayr and her colleagues (Heidlmayr et al. 2014) proposed the hypothesis that these differences in results may be due to a central factor which is not always taken into account in behavioural experiences: the relative frequency of language use in the different bilingual groups tested.

2.6.1.1 The enhancement effect of code-switching on executive functions

The alternation between languages, as well as the suppression of one of them in parallel activated languages, has an impact on Executive Functions in bilinguals. The link between the code-switching and the bilingual advantage (Costa et al. 2009) has been one of the central points of the debate about what methods bilinguals use to keep their languages separate and code-switch in appropriate settings.

In bilingual conversations, speakers often have to keep track of which language to speak to: this activity may entail monitoring processes of the sort involved in Executive Functioning in general, and consequently may be the basis of the bilingual advantage in this domain. If code-switching is controlled by the same mechanisms as those used by monolinguals to switch between tasks, then code-switching trains EFs (Green 1998). Moreover, different code-switching types can be distinguished by the level of activation or separation of both languages and qualitatively different code-switching types employ different EFs: for example, in situations of language separation (the beginning of the sentence in L2 and the end in L1) code-switching involves inhibition and switching; whereas, language co-activation (a combination of L1 and L2 words within the same sentence) mainly concerns opportunistic planning and conflict monitoring.

On this subject, Green and Abutalebi (Green and Abutalebi 2013) proposed the Adaptive Control Hypothesis (ACH) to show the role of interactional context in EFs modulations. They identify three contexts: the single language context, the dual language context and the dense code-switching context. In the single language context, bilinguals use one language exclusively in context A (for example at work) and another language in context B (for example at home), with very little code-switching between languages. In dual language context, different languages are used with different locutors, so code-switching may take place but only between utterances (inter-sentential code-switching); and in dense code-switching context, speakers freely mix both languages within one utterance (intra-sentential code-switching).

In each context, different cognitive functions are mainly used; thus, in the single language context there is a strong demand on inhibition and monitoring; in the dual language context, inhibition, switching and monitoring are required, since both languages are used depending on the topics, situations or speakers; and in the dense code-switching context any inhibition nor monitoring is needed, but opportunistic planning, which means “making use of whatever comes most readily to hand in order to achieve a goal” (Green and Abutalebi 2013).

Therefore, the ACH predicts idiosyncratic variability in code-switching patterns based on linguistic contexts: this variable seems to have an impact on executive functions, too. In fact, Hofweber and his colleagues (Hofweber, Marinis, and Treffers-Daller 2016) analysed conflict monitoring skills needed to construct an utterance containing words from two languages. Their results demonstrated a negative correlation between dense code-switching scores and monitoring costs, since the more frequently participants indicated they densely code-switch, the better they performed at conflict monitoring. Consequently, code-switching provides benefits to cognitive control.

2.6.2 Executive control, inhibition and selective attention

The way in which bilingualism influences cognitive control has been at the center of several studies: Bialystok and his colleagues (Bialystok et al. 2004; Bialystok and Martin 2004) have been the pioneers of this field of studies, testing monolinguals and bilinguals in cognitive tasks. Their results showed better interference suppression, connected to an inhibitory control advantage, and faster reaction time (RT) in both tasks requiring and not requiring interference suppression. These benefits were, thus, broader in cognitive control.

Thereafter, several studies have been conducted: the data demonstrated that various cognitive processes benefit from bilingual experience, notably inhibition, attention (Grundy et al. 2017; Fan et al. 2002; Costa, Hernández, and Sebastián-Gallés 2008) and executive control (Fan et al. 2009; Bialystok et al. 2004; Bialystok, Craik, and Luk 2008; Marzecová et al. 2013). In most of the cases, bilinguals outperformed their monolingual counterparts, with faster global RTs, greater accuracy and less interference in incongruent trials. However, these bilingual benefits were not equally distributed within all cognitive abilities, with some of them more improved than others. Findings from various studies proved this effect (Costa, Hernández, and Sebastián-Gallés 2008; Costa et al. 2009; Hernandez, Bates, and Avila 1996; Hernández et al. 2010; Marzecová et al. 2013), supporting the assumption proposed by Bialystok et al. 's (Bialystok, Craik, and Luk 2008) that different features of cognitive control are impacted differently. Thus, the bilingual cognitive advantage is not homogeneous and does not extend to all cognitive functions.

Inhibition is a cognitive ability particularly enhanced by bilingualism, since the bilingual speaker needs to constantly inhibit the unwanted language in order to allow processing in the target language. Bilinguals exercise this control at two levels (Green 1998): at a high level, when a language is selected and the other is inhibited, and at a lower level, when the lexical forms of the target language are activated and the translation equivalents, in competition, are inhibited.

The model of executive functions proposed by Miyake and colleagues (Miyake et al. 2000), already mentioned, represents a theoretical proof of the enhanced inhibition processes due to bilingualism. Moreover, inhibition plays a central role in bilingual cognitive performance since language joint activation requires a mechanism of language selection. This effect has been identified in non-verbal cognitive performance, too (Bialystok 2001): the presence of a bilingual advantage in cognitive domain-independent ability has been attested by better performances in non-linguistic interference tasks. Thus, all these types of evidence support the theory that global enhanced inhibitory control is a consequence of the inhibition in bilingual experience.

2.6.2.1 Selective Attention

The advantage provided by the bilingual experience on executive control is generally assigned to the bilingual daily mastering of two different languages, which compete with each other for attention (Kail 2015). In the conceptualisation of attention, the most influenced model has been the one proposed by Posner and colleagues (Posner and Petersen 1990) in which the attention system is separate from other processing systems and identifies three subsystems. Each of them is responsible for separate functions and depends on specific brain regions: alerting, orienting and executive control. Alerting is involved in the maintenance of an attentional status and in the preparation for an incoming stimulus; orienting concerns the selection of information among distractors based on a sensory stimulus; finally, executive control deals with conflicts in attentional decision making. Although the three attentional networks are functionally and anatomically independent, they operate in a constant interdependent influence in order to produce an accurate and efficient behaviour. Thus, these disparate networks are collectively responsible for the different cognitive functions related to attention mechanisms.

Various studies have been conducted to assess the efficiency and interactions of these three subsystems, as well as to prove the impact of bilingualism on all the functions of

attentional control (Costa, Hernández, and Sebastián-Gallés 2008). Attentional network tasks (ANT) have been the most frequently used to examine the three components of attention (Hussain and Wood 2009; Fan et al. 2002; Costa et al. 2009). Starting from the results they obtained, the authors made the hypothesis that bilingualism modifies not only inhibitory processes, but also the behavioural readjustment and regulation processing, as well as the mechanisms facilitating the correct response during the entire lifespan of bilingual individuals.

2.6.2.2 Bilingual behavioural tasks

Heterogeneous findings about the effects of bilingualism on cognitive control can be due to the so-called “task impurity” problem (Miyake et al. 2000; Miyake and Friedman 2012; Valian 2015) which illustrates the impossibility to create one specific task to study one component of the cognitive control (Kroll and Bialystok 2013). At the same time, it is also complicated to mix and/or match different tasks; in fact, some tasks appearing similar may not require the same processing abilities (Valian 2015) and between-group differences may also be influenced by cognitive control differences. Thus, it is not easy for the experimenter to be sure whether the task he/she is using is an actual indicator of the cognitive processes it is supposed to measure.

An additional factor of difficulty in the definition of the experimental protocol is the complexity of the task itself. As Costa (Costa et al. 2009) demonstrated, some experimental conditions can affect the outcomes in non-linguistic tasks. For this reason, some authors have sometimes adjusted and modified their experimental protocol, adapting it to the task’s costs of their groups of participants through the creation of different levels of difficulty (Wu and Thierry 2013; Sabourin and Vinerte 2015).

Thus, in the design of experimental tasks in cognitive control studies, different factors need to be taken into consideration; difficulties in the analysis of the cognitive processes used in a specific task, the possible manipulation of experimental conditions on the

obtained results and the identification of the locus of each process continue to be a challenge for the research on bilingualism and cognitive control.

However, there exist some defined tasks used to test executive control in verbal and non-verbal cognition which are worldwide used: the Stroop task, the Simon task, the Flanker task and the ANT task. In such tasks involving executive control, the inhibition hypothesis predicts that bilinguals perform better in incongruent trials, which include distractors, but not in congruent trials that do not, compared to monolinguals.

Studies on conflict monitoring, inhibition and attention tasks found that globally bilinguals reported better performance than monolinguals: they, in fact, are more efficient in shifting the attention to select the correct response, have better goal maintenance scores, have a great capacity to monitor different components of executive function and have shorter mean RTs (Bialystok, Craik, and Ryan 2006; Colzato et al. 2008; Costa et al. 2009; Morales et al. 2015; Morales, Gómez-Ariza, and Bajo 2013; Teubner-Rhodes et al. 2016; Treccani et al. 2009; Parra et al. 2009; Prior and MacWhinney 2010; Hernández et al. 2013; Soveri, Rodriguez-Fornells, and Laine 2011; Greenberg, Bellana, and Bialystok 2013).

However, even in this field of studies, many researches did not show the same effects, failing to find differences between monolinguals and bilinguals in executive functions performance (Paap and Greenberg 2013; Paap and Sawi 2014; Gathercole et al. 2014; Kalia, Wilbourn, and Ghio 2014; Kousaie and Phillips 2012; Kousaie and Phillips 2012; Kousaie et al. 2014; Prior and Gollan 2013; Scaltritti, Peressotti, and Miozzo 2017; von Bastian, Souza, and Gade 2016; Antón et al. 2016; De Bruin, Bak, and Della Sala 2015; Kirk et al. 2014). A plausible interpretation of these consistent differences in results may include the participants' selection and definition as monolinguals and bilinguals, the statistical methods used to analyse data, the interpretations of the results and the features of the task (Cox et al. 2016; Kroll and Bialystok 2013).

2.6.3 Models of bilingual language processing

To assure the fluent use of the correct target language, the joint activation of the two language systems in the bilingual speaker needs a mechanism for language selection. This mechanism is supposed to be part of a domain-general system responsible for language control and fortifies other non-verbal processing, too (Bialystok et al. 2009; Abutalebi and Green 2007; De Baene et al. 2015; Luk et al. 2012). The functioning and structure of this general system is still debated, as well as other aspects concerning the bilingual language processing like the strategies and the decision criteria during a specific task.

Different computational and theoretical models have been proposed to describe language processing in bilinguals, especially to explain how the selection system operates. In this section, we will analyse three of the most influential models: the Green's Inhibition Control Model (Green 1998), the Bilingual Interactive Activation Model (BIA) and the Bilingual Interactive Activation Plus Model (BIA+).

2.6.3.1 The Inhibition Control Model

In his Inhibition Control Model (IC), Green (Green 1998) assumes that a Supervisory Attentional System (SAS) controls, in a top-down way, the processing and the activation of lexical and phonological units during linguistic and non-linguistic tasks. This top-down inhibition control allows the selection of the target language in the L1 and L2 competition, avoiding interlinguistic interference in the language coactivation. The process of language control operates through multiple control levels: the activation of each language system is regularized by linguistic tags which are controlled by the SAS. Language processing results from linguistically and contextually appropriate representations.

Green's model is based on the central role of inhibition on bilingual language processing and on cognitive functions in general. Thus, if the hypothesis that SAS constitutes a

general inhibition control on language selection in a multilingual environment is valid, then the use of several languages may represent a training for the mechanisms of control. For this reason, bilinguals have an advantage on monolinguals in a top-down inhibition control: they are more efficient in the suppression of the less dominant language, compared to their dominant one, when the two languages are in competition.

The goal of Green's model is to provide an account of the bilingual control system which allows him/her to behaviourally and efficiently perform. He tried to explain how bilinguals manage and engage their two languages during daily conversations, in monolingual and bilingual discourse, including code-switching. The translation processing from L1 to L2 and inversely, is in Green's perspective asymmetric: this asymmetry is due to the unbalanced activation of L1 and L2 representations. In fact, the greater activation associated with the first language rather than the second language requires a stronger L1 suppression to avoid the production of the L1 word in a L2 linguistic context. In contrast, the process of suppressing L2 to speak L1 requires less resources and less time, since L2 produces less activation than L1.

Green suggests that the inhibition of the first language is produced by an L2 schema which suppresses the activated L1 lemmas. In fact, in the IC Model (Figure 25), we find multiple levels of control associated with a specific schema: from high-level to a low-level. It specifically operates at an intermediate level, the lemma level, where the inhibitory system suppresses the activation of lemmas tagged in the unwanted language. The notion of language tags is crucial in the functioning of this mechanism since they belong to the conceptual system of the lexicon, allowing language discrimination and selection.

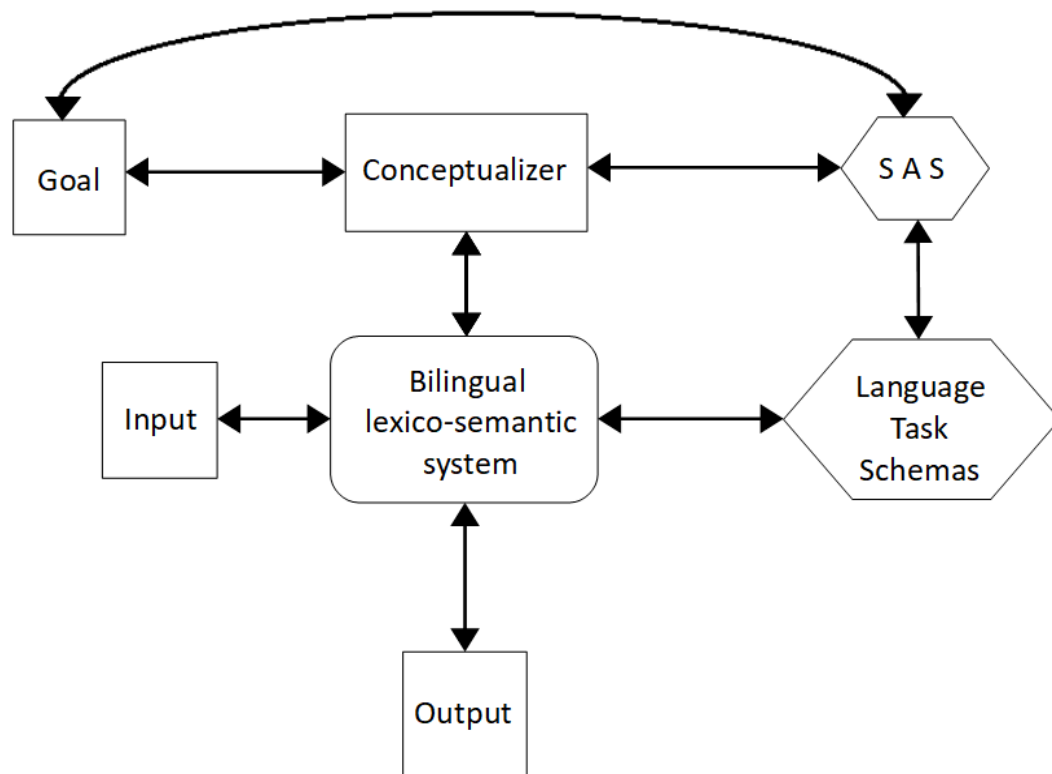


Figure 25: The Inhibitory Control Model by Green (Green 1998).

2.6.3.2 The Bilingual Interactive Activation Model (BIA Model)

The second model we present in this section is the one proposed by Dijkstra and van Heuven (Dijkstra, van Heuven, and Grainger 1998) called the Bilingual Interactive Activation Model, or BIA model.

As in the IC Model, the authors assume the initial coactivation of the two languages in the bilingual individual: the resolution of the competition between the candidates can be inhibited in a top-down way. The words of the non-target language are suppressed through language nodes, which are the main distinctive feature of this model. Each node collects activation of all words from one lexicon and suppresses all words in the other lexicon, with asymmetric inhibition of words in the two languages, since L1 words can be more inhibited than L2 words. When a node becomes more salient than the others, it inhibits the lexical representations associated with the other language nodes until a new

node becomes salient. Thus, language nodes reinforce lexical activation of the target language, decreasing lexical activations in the other lexical system.

Two central aspects differentiate the IC model and the BIA model: the first one concerns the localisation of the levels of control in the language selection and inhibition. While the IC model predicts a top-down inhibition system, the BIA model (Figure 26) introduces an automatic system of inhibition. The second one involves the bilingual advantage: the IC model postulates the bilingual advantage in linguistic and non-linguistic tasks, whereas the BIA model considers that this advantage concerns only linguistic components.

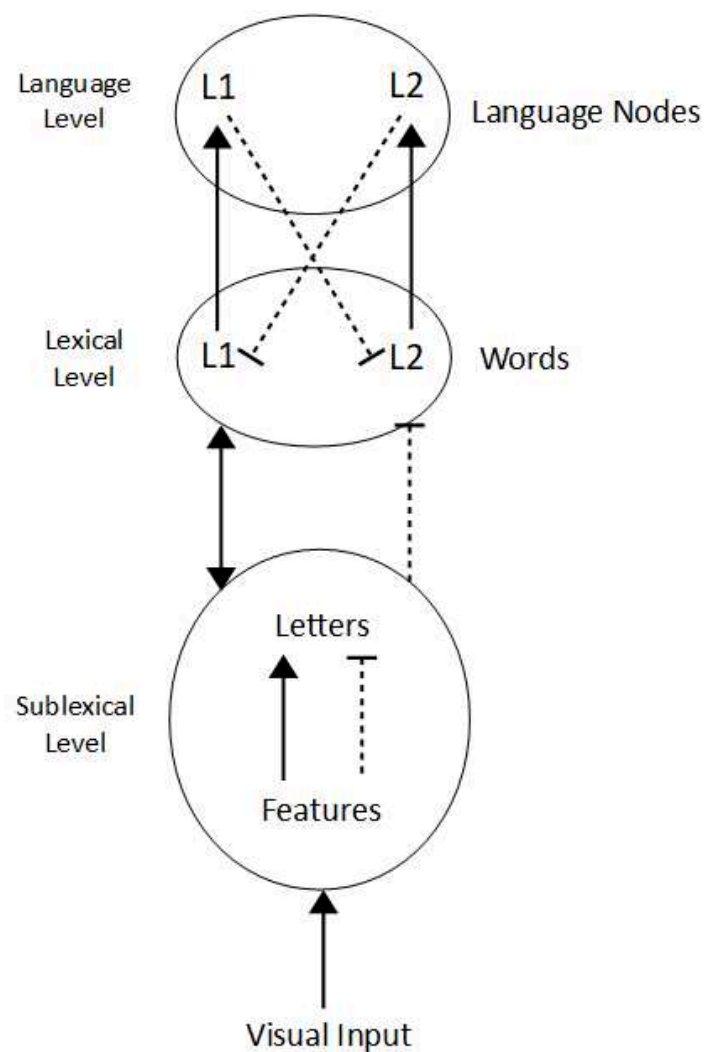


Figure 26: the BIA Model by Dijkstra and van Heuven (Dijkstra, van Heuven, and Grainger 1998).

2.6.3.3 The Bilingual Interactive Activation Plus Model (BIA+ Model)

The last model for bilingual language processing is an extension of the BIA model; for this reason, it is called the Bilingual Interactive Activation Plus Model (BIA+ model), developed by Dijkstra and Van Heuven (Dijkstra and Heuven 2002). This model revised the role of the language nodes and defines the bilingual language processing as a bottom-up mechanism.

Two interactive subsystems are described in this account: the word identification subsystem and the task/decision subsystem. When the bilingual individual receives a stimulus, the visual input activates the word orthographic, phonological and semantic representations in the two languages; this co-activation is possible since the lexical access is nonselective. Once the word has been recognised and the language nodes have been activated, the information is then used in the task/decision subsystem that determines which actions must be executed for the current task, based on the relevant information.

In the BIA+ model, the language tags are active at a post-lexical level, not during the activation level of the word representation. In fact, these nodes enable bilinguals to avoid as much negative interference from the unwanted language while processing in the target language.

Moreover, the language processing is based on contextual features and relevant codes which determine decision criteria to produce an appropriate response. Language selection in the BIA+ model depends on differences between L1 and L2 activation levels: the authors assume that the L2 is generally activated to a lower level than the L1 in bilingual use. As a result, the L2 takes more time to be activated than the L1, due to a delayed access to phonological and semantic information in the L2 compared to the L1. This process is called the Temporal Delay Assumption constructed on variations in L1 and L2 activation at rest: this difference is, in fact, caused by differences in frequency of use and language dominance.

Although the BIA model and the BIA+ model have several similarities in common, two main distinctions exist between the two: the first concerns the bottom-up nature of the BIA+ control mechanism which assumes that the word identification system cannot be

influenced by the information from the task/decision subsystem, whereas in the BIA model the two subsystems bidirectionally interact. Secondly, while in the BIA model the language nodes play a central role in inhibition, in the BIA+ model (Figure 27) they do not affect the word recognition system at the activation levels.

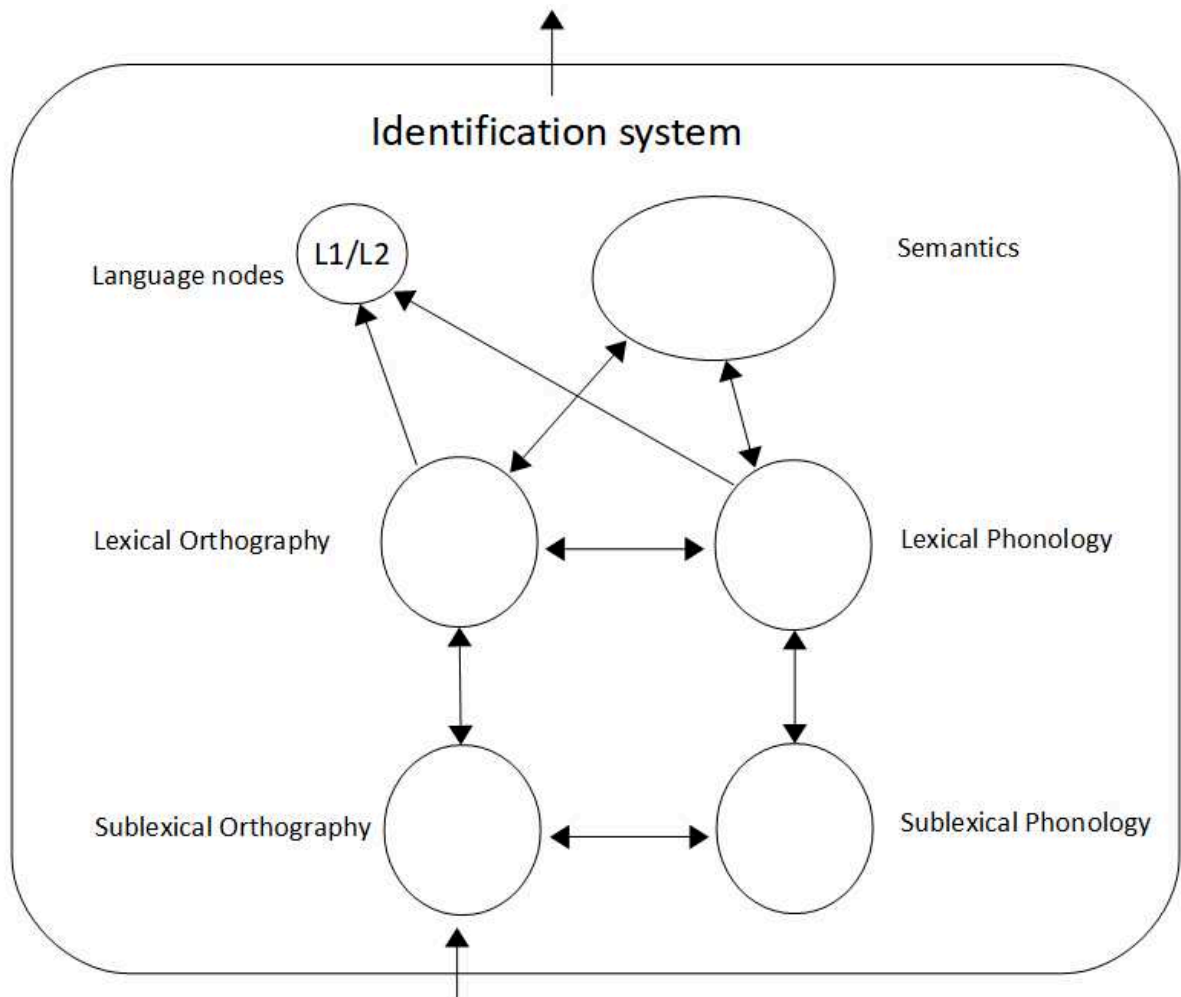


Figure 27: The BIA+ Model by Dijkstra and Van Heuven (Dijkstra and Heuven 2002).

2.6.4 The bilingual advantage in the Color Word Stroop Task

The frequent code-switching of bilingual speakers in their daily lives is considered to be a factor of training of their inhibitory control; in fact, they would solve conflicts in an easier way than monolinguals (Badzakova-Trajkov, 2008; Bialystok et al. 2004; Bialystok, Craik, and Luk 2008); Costa, Hernández, and Sebastián-Gallés 2008). This advantage would produce reduced interference effects and faster response times in executive tasks, like the Stroop Color Task (Stroop 1935). Although we still lack a well-defined and worldwide accepted account on the beneficial effects of bilingualism on conflict resolution and inhibitory control, the Color Word Stroop Task rests one of the more exploited tasks to study between-group differences in conflict resolution processing. In fact, in this study participants have to make decisions based on task-relevant information while distractor information is simultaneously present. As Bialystok affirms (Bialystok, Craik, and Ryan 2006, p. 1342) “two conflicting mental representations are active, each associated with a different response, and attention must be paid to only relevant cues”. Subjects have to identify the ink color while ignoring the written word. To do that, a greater amount of attentional resources are required for color naming than for word reading (Coderre, Heuven, and Conklin 2013; Kousaie and Phillips 2012), since the former is a controlled process demanding executive cognitive control, whereas the latter is an automatic process needing little effort (LaBerge and Samuels 1974).

During a parallel process, this control is reflected in slower response times in incongruent trials, or when the ink color and the color word do not match, compared to congruent trials, since the diverging word and the chromatic information compete in the decision task. The conflict is caused by the fact that a controlled process (color naming) is disturbed by an automatic process (word reading): interference arises (MacLeod and MacDonald 2000). Thus, it takes more time to name colours in the incongruent condition: this increased latency in naming has been called the “Stroop effect”.

Studies which used this experimental protocol interpreted slower RTs in the incongruent condition (a smaller Stroop effect) as the index of stronger inhibitory control (Badzakova-Trajkov 2008; Pardo et al. 1990; Bruchmann et al. 2010; Coderre, Conklin, and van Heuven 2011; Liotti et al. 2000; Naylor, Stanley, and Wicha 2012; van Veen and Carter 2005). The

“Inhibition effect” was, thus, defined as the difference in reaction times between the incongruent condition and the neutral condition (Coderre, Conklin, and van Heuven 2011; Badzakova-Trajkov et al. 2009; Qiu et al. 2006).

At the same time, a facilitation effect has been identified, too: in the congruent condition, in fact, the ink color and the word color are the same. Faster reaction times have been registered for congruent trials compared to neutral trials, showing general language processing: the “Facilitation effect” was defined as the difference in reaction times between the congruent condition and the neutral condition (Badzakova-Trajkov et al. 2009; Coderre, Conklin, and van Heuven 2011; Hanslmayr et al. 2008; MacLeod and MacDonald 2000).

Several studies have modified or extended the protocol of the Stroop Color Word task to additional components or language groups (for example, Early Sequential Bilinguals versus Late Sequential Bilinguals, in Sabourin and Vinerte 2015) to identify what kind of advantages in linguistic cognitive control are connected to bilingualism (Sabourin and Vinerte 2019). Different aspects linked to the bilingual experience have, thus, been examined: the results have globally showed that the bilingual advantage is moderated by diverse interconnected factors, like education, age of second language acquisition (AoA), age of immersion in a L2 linguistic environment (Aol) (Heidlmayr et al. 2014), frequency of use, proficiency and language exposure, as well as task complexity (e.g., a language mixed Stroop task) (Costa et al. 2009; Wu and Thierry 2013). Such components have a central role in determining performance in linguistic and cognitive control in tasks of inhibition control, like the Stroop Color Word task.

2.6.5 The failure of the bilingual advantage effect on Executive Processing

The assumption that bilinguals have enhanced abilities in general cognitive control due to their extensive practice in language switching, monitoring, selection and inhibition has

been largely investigated. As we have already seen, several studies (Bialystok 2006; Bialystok et al. 2004; Bialystok, Craik, and Luk 2008; Costa, Hernández, and Sebastián-Gallés 2008) have reported a bilingual advantage in tasks requiring executive processing (EP), which is the ability to monitor and switch attention to goal-relevant information, inhibiting the irrelevant or competing ones (Hilchey and Klein 2011).

However, many studies did not observe this bilingual advantage in EP: Paap and Greenberg (Paap and Greenberg 2013) empirically demonstrated this failure through the replication of three experiences, notably a Flanker task, a Simon task and a color-shape switching task. The authors, in fact, assumed that tasks and measures typically used to test differences between monolinguals and bilinguals in inhibitory control did not provide robust evidence for the same enhanced general ability. In other words, the non-linguistic interference tasks generally used in this kind of experiment typically provide only a single measure of one EP component, since the same groups of matched bilinguals and monolinguals participate in only a single task. Thus, any significant correlation above these tasks is present: correlations in individual differences are generally low and depend on task features (Friedman et al. 2008).

The main purpose of Paap and Greenberg (Paap and Greenberg 2013) was to demonstrate the presence, or the absence, of a real bilingual advantage in executive processing, using three large samples of participants who were tested in all the tasks and making multiple comparisons correlating task features and the associated specific EP component.

Their results showed null or no cross-task correlations: the effects assumed to be indicators of a specific executive process (e.g., the inhibitory control) cannot be interpreted as a valid measure of domain-general abilities. The authors postulated that bilingual advantages registered in previous research mainly depended on the EP component measured, on the type of bilingual group tested and on the task used. These empirical inconsistencies showed the evidence that, when a bilingual performance advance occurred, it was likely attributable to factors enhancing EP other than bilingualism, as reported by other studies, too (Morton and Harper 2007; Morton and Harper 2009; Tare and Linck 2011; Morton 2010).

Paap and Greenberg (Paap and Greenberg 2013) concluded that there is no evidence for assuming that the bilingual experience enhances general and domain-independent EPs: even studies using multiple non-linguistic tasks with the same matching groups did not show any convergent validity. To further test the bilingual advantage in Executive Processing, new experimental protocols should be constructed, taking into account some crucial factors, notably the identification of EPs' specific components enhanced by bilingualism, the presence of a cross-task bilingual advantage for an indicator of a specific component, the correlation between indicators, the homogeneity of the experimental groups, as well as the minimization of participants' cultural differences and social-economic status.

Conclusions

As we saw in this chapter, bilingualism is a complex phenomenon determined by several factors in inter-dependent relations subjected to variations in the bilingual's lifespan. Various fields of study have conducted different kinds of structural, behavioural and neurophysiological studies in order to identify its functioning and cognitive benefits.

As we have seen, bilingualism is not a categorical variable (Luk and Bialystok 2013): differences between and within the same group of speakers can strongly affect language treatment and cognition. In fact, if some bilinguals are dominant in their native language, others are dominant in their L2; some bilinguals code switch in their daily life, whereas others not; some bilingual speakers live in a communicative context where others are similarly bilingual, others do not. Since context may determine the way in which bilinguals recruit cognitive resources, the bilinguals' mastering of their languages has an impact on language use, the mental processing it involves and the neural structures it exploits. Thus, the two, or more, languages are dynamic and differ across bilinguals within an adaptive

system: the mother tongue can affect and be affected by the second language, revealing that individual variations can differentially contribute to the linguistic and cognitive processing in a constant contrastive approach to the corresponding monolingual counterpart.

In this chapter, we also made a global analysis of all the components associated with the bilingual experience, explaining the main theoretical debates involving language learning and second language acquisition, as well as the question of critical age (Lenneberg 1967) and the bilingual advantage hypothesis. Cognitive language models proposing the different bilingual structural solutions to represent the surrounding world have been illustrated: do bilinguals have a shared concept storage for the two languages or do their languages belong to distinct representational reservoirs? These questions, like many others focusing on the bilingual effect on executive functions, are still not completely solved.

Looking globally, it is evident that a great number of variables shaping human cognition and brain organization need to be considered: there is clear evidence that bilingualism has a coherent complexity which is adapted to its unique situation.

PART III: The Experimental Design

Chapter 3: Research Topic and Methods

Introduction

In this second part of the manuscript, we will present our research project in detail, as well as the methods adopted in our experimental protocol with the collected data.

The aim of the present study is to investigate the impact of linguistic categories and cognitive factors on color perception, notably for the blue color boundaries which seem to be an exception in several languages in the color spectrum.

This chapter, thus, starts with the description of our project accompanied by the objectives of our study and the hypothesis we made; in the second section, we will report the two experiments adopted to test participants, the methods of our data collection, as well as the parameters used to analyse them. Special attention will be dedicated to the speakers' characteristics of the three groups of participants who have participated in our study.

Some general conclusions will complete the last part of this section.

3.1 The Present Study: Italian vs French Blue Semantics

The findings of all the works conducted on color perception have put evidence on the relationship between cognition and linguistic conceptualisation. In this context, bilingualism plays a central role for the investigation of the impact of language on categories' representation, as well as on the universality of color foci through the study of the semantic shift of language-specific categories from the first language to the second language (Ratner 1989; Saunders and van Brakel 1997; Lucy 1997; Pavlenko 2005; Kay, Berlin, and Merrifield 1991; Kay et al. 1997).

Starting from the assumption that color boundaries are cross-linguistically arbitrarily defined, if two colours are named with the same word in one language, speakers of that language will judge them more similar than speakers of another language, assigning them two distinct color words.

Focusing on the study of the basicness of the two Italian blue terms *blu* and *azzurro*, we will analyse, in a contrastive approach, whether there currently exists differences in French and Italian monolingual speakers in the way they perceive colours falling in the blue spectrum, according to their different linguistic partitioning of the color space (*bleu* vs. *blu* and *azzurro*). Our findings will bring additional evidence to the assumption that Italian has twelve BCTs and that *azzurro* names a specific independent region of the blue spectrum, corresponding to lighter hues, that in French falls under the color word *bleu*: French is, thus, one of those languages which lack the linguistic distinction between light blue hues and dark blue hues.

The bilingual group under investigation will allow us to put evidence on the real existence of a perceptual distinction affected by linguistic marks, since color representation would be determined by L2 blue categorisation. This would indicate that learning a different color vocabulary may cause shifts towards language-specific patterns. Therefore, conceptual representation is not fixed by the L1, but pre-existing L1 properties can change with the acquisition of new L2 specific features, producing a cognitive reorganization.

In our case, if L1 color cognitive representation is affected by the L2, French-Italian bilinguals will adopt the Italian blue linguistic partitioning of color space both in French tasks and in fully perceptual non-linguistic tasks.

Bilinguals' data will be compared to those of French and Italian monolinguals, taking into account some variables which can have an impact on perceptual and cognitive behaviour (Athanasopoulos and Kasai 2008), like the level of L2 proficiency, the length of stay in a L2-speaking country, the age of L2 acquisition and the frequency of L2 use. All these factors will also determine the degree of impact of bilingualism on color cognition. In our research, the bilingual group of participants is composed of French speakers who have learnt Italian from birth and/or during their education. Their L1 is, thus, French and their L2 is Italian.

Moreover, Italian and French are two typologically similar languages whose different partition of color space into language-specific categories could have an influence on color perception: our investigation would, thus, demonstrate that typological distance between languages can have different degrees of influence on the bilingual cognitive shifts towards the L2. All these arguments have, in fact, important effects on the global conceptual representation functioning in bilinguals (Francis 1999; Pavlenko 1999; Groot and Christoffels 2006; Cook 2003), showing that they can vary under the influence of a set of variables linked to the salience of specific linguistic categories of the bilinguals' L1 and L2.

Research, as once conducted by Andrews (Andrews 1994) with Russian-English bilinguals, has shown that bilinguals' L2 can influence the color categorisation of their L1, with some variables (e.g., the age of L2 acquisition, L2 proficiency, social-economic status, the duration of immersion, and others) being crucial for understanding the impact of linguistic features on cognition in general, and through the analysis of the way in which bilingualism controls the cognitive functions. In various studies (Cook et al. 2006; Athanasopoulos 2006; Athanasopoulos 2007; Athanasopoulos and Kasai 2008; Boroditsky 2001), the length of stay in a L2-speaking country, the L2 age of acquisition and the L2 high proficiency had a significant effect on cognitive behaviour in linguistic and non-linguistic tasks, like time perception or picture similarity judgments, especially in bilingual categorisation.

Globally, the bilingual linguistic and cognitive behaviors vary with the language system used. Each language, in fact, categorizes the external world in a specific way that determines the way in which grammatical and lexical labels influence different aspects of perceptual processes (Malt and Sloman 2003; Ameel et al. 2005; Roberson et al. 2005).

Bilingual categorisation is, thus, at the heart of the current study where color perception is investigated. We want to analyse the way in which color representation and perception are affected by language, especially when the subject masters two, or more, different linguistic systems which code and partition the color space in distinct ways.

Our study leans on previous works whose results have demonstrated that the L2 strongly influences the use and the color prototypes of the L1 color words in bilinguals through semantic shifts. Bilinguals' use of L1 color terms can, in fact, be different than the

corresponding monolingual groups (Erwin et al. 1961) or they can shift the L1 color terms prototypes towards the L2 prototypes (Caskey-Sirmons and Hickerson 1977) or can even modify the color naming behaviour of their L1 based on the distinctions made in their L2 when their systems diverge, for informative purposes (Jameson and Alvarado 2003).

“The worldview of bilinguals, whatever their first language, comes to resemble, to some degree, that of monolingual speakers of their second” (Caskey-Sirmons and Hickerson 1977, p. 365).

Therefore, bilinguals can differ from monolinguals in the way they partition the color space, and they use the color lexicon specific to their L1 and L2, with consequences on cognitive and perceptual representation of color categories.

The current study considers bilingualism as one of the main factors capable of restructuring the cognitive framework of the bilingual mind in color perception and categorisation (Cook 1997, 2002, 2003; Green 1998; Pavlenko 2005, 1999). The central question concerns the influence of language on cognition and perception even in non-linguistic domains. Mastering two different linguistic systems with distinct color categorical divisions has, indeed, an impact on the representation of these categories on the bilingual mind.

Three groups of subjects have been tested in two behavioural experiments: one group of French monolinguals living in France, one group of Italian monolinguals living in Italy and a group of French-Italian high proficient bilinguals living in France.

The current study aims, thus, to analyse this tight relation between cognitive behaviour and linguistic labelling in an extra-linguistic domain, like color perception, where bilingualism ensures a deep exploration of the cognitive differences between subjects of different languages with distinct world categorisation. Through a cross-linguistic investigation, we will try to prove that there exists an effect between specific color words and the perceptual color hues they name in the worldwide discussed debate involving the partitioning of the blue spectrum.

3.1.1 Global Research Objectives

As we explained in the previous chapters, the universalist approach of color categorisation (Berlin and Kay 1969; Kay and Maffi 1999) and the opposing relativistic view (Whorf 1956; Saunders and van Brakel 1997) have found a compromise in the weak relativity hypothesis for which different kinds of factors, linguistic, perceptual and social, play a role in color cognitive processing (Roberson et al. 2005).

One of the main objectives of the present study is to bring increased evidence for the weak relativity theory with the possibility of the emergence of additional Basic Color Categories (BCCs) linguistically labeled by new Basic Color Terms, beyond the 11 BCTs identified by Berlin and Kay. Based on these assumptions, color perception is influenced by the language spoken, even in the comparison of languages typologically similar.

At the same time, we aim to empirically demonstrate the existence of a 12th Basic Color Term in Italian, notably *azzurro*, which identifies the light blue hues of the color spectrum, like other languages do (e.g., Russian, Japanese, Maltese, Greek, Catalan). It would, thus, be possible to compare the linguistic and perceptual systems of French and Italian languages in the blue semantics, providing further experimental knowledge about the effects of the phenomenon called categorical perception (CP) in color perception (Goldstone and Hendrickson 2010; Harnad 1987).

Lastly, our project intends to furnish additional information about the bilingual linguistic and cognitive functioning, especially for the debate about the presence of a bilingual cognitive advantage. Through the analysis of the lexical and cognitive evolutionary steps of two or more languages mastering, we aim to identify the adaptation and interiorization processes of a new conceptual system, especially in the color perception field of study.

3.1.2 General Hypotheses

Starting from the results obtained by several color naming studies, as well as on color cognition, we would expect to collect data showing that lexical categorisation has an impact on the partitioning of one language chromatic space. This phenomenon would appear particularly clear in the way Italian and French share their blue color spectrum, attesting that language can play an active role in extra-linguistic tasks, notably in perceptual tasks.

Behavioural data analysis would reveal that the two Italian BCTs for the two distinct hues (light and dark) determine the presence of a category advantage (CA) in Italian monolingual speakers and French-Italian bilingual speakers in the perceptual discriminations of colours belonging to distinct lexical categories. We expect that this category advantage would be absent in French speakers' color discrimination, too.

Categories could, thus, facilitate the identification of cross-category color stimuli compared to within-category color stimuli, but cognitive factors, like mnemonic and attentional allocations (Christoph Witzel and Gegenfurtner 2018), could also play a central role in the perceptual processing of color differences, through a facilitatory effect.

Meanwhile, our additional hypothesis about bilingualism is that people mastering two linguistic and conceptual systems, always adopt the categorical differentiations of the language owning the lexical distinctions, even though it is their second language. In the present study, we expect that French-Italian advanced bilingual speakers use the Italian conceptual system, where there exists a linguistic distinction between two perceptual blue hues, even for tasks involving their mother tongue (French) and in exclusively perceptual tasks. Consequently, the level of proficiency in one language (Italian) determines the performance in the reaction to chromatic stimuli in the blue color spectrum.

More detailed hypotheses about the phenomenon studied will be explained in the next section of this chapter, where each experiment is described and discussed.

3.2 Experimental Methods

In this section we will present the methodology used to obtain data from the experimental protocol of our research, based on a double comparative study, both lexical and perceptual. Our main purpose is to analyse the differences in color categorisation and discrimination from a linguistic and a perceptual point of view, through two perceptual tasks, in monolingual and bilingual speakers.

Three groups, two groups of monolinguals and one group of bilinguals, performed the same tasks: we aim to understand the impact of the differences in the lexical categorisation of the blue color space in French and Italian monolingual speakers on color perception, as well as in which way these differences are managed from the bilingual mind. This aspect will allow us to study the lexical and cognitive evolution of the second language acquisition processes, including the cross-linguistic influence from first language to the second language and/or inversely.

The data obtained at the end of the experiments provide a global portrait of the functioning of lexical access and the perception mechanisms in speakers managing one language or two languages, having different basic color categories, calling into question the influence of language on perception. The effects of language can, in fact, modulate, in a top-down way, visual decisions in different kinds of tasks with more or less strong effects (Martinovic, Paramei, and MacInnes 2020).

The two experiments performed by participants are a Word Color Stroop Test and a Speeded Colour Discrimination Task, inspired by the studies conducted by Winawer et al. (Winawer et al. 2007), with some modifications. We will explain in detail the two experiments in the following sections of this chapter, providing information about the participants, the materials and the design used, as well as the procedures and the data analysis made.

Before planning the experience, participants completed a questionnaire concerning their linguistic history, inspired by the model of *Li, P., Zhang, F., Yu, A., & Zhao, X. (2020)*.

Language History Questionnaire (LHQ3): An enhanced tool for assessing multilingual experience. Bilingualism: Language and Cognition, 23(5), 938-944, where personal and professional information are collected. Bilingual participants also completed a second language background questionnaire on their linguistic uses and habits relating exclusively to French and Italian, inspired by the model of *Birdsong, D., Gertken, L.M., & Amengual, M. (2012). Bilingual Language Profile: An Easy-to-Use Instrument to Assess Bilingualism. COERLL, University of Texas at Austin*, and passed a linguistic test in order to define their linguistic proficient level in Italian. The linguistic placement test used was the one conceived by the AIL institution (Accademia Italiana di Lingua), based on the AIL official syllabus for foreign speakers, which contains 76 grammatical and lexical questions becoming more and more complex. The final score corresponds to a one of the linguistic levels established by the CEFR¹.

Before starting the experiments, subjects passed two pre-tests: the first one is the most well-known color vision test based on pseudoisochromatic plates, or the Ishihara Color Blindness Test, designed to detect eventual color perception deficiencies. The second pre-test is a barrage test, or a cancellation test, mostly used in psychometry to detect attention deficit disorders. The main task is, in fact, to strike out as quickly as possible one or more specified symbols, which can be letters, digits or geometrical figures, irregularly distributed among others.

The entire experimental protocol has been validated by the directors of the PNAV pole (Psycholinguistique, Neurocognition, Acquisitions et Variations) of the MoDyCo Laboratory in the University of Paris Nanterre.

3.2.1 Participants' characteristics

The participants' groups composition has been the first step for our data collection and analysis in order to make successive comparisons. Participants have been divided in three

¹ Common European Framework of Reference for Languages

main groups: two groups of monolinguals, one made of French monolingual speakers and one of Italian monolingual speakers, and one group of French-Italian proficient bilingual speakers. Each group was composed of about 22 adult participants, for a total of 66 participants.

All the participants reported normal vision or corrected-to-normal vision and had no color blindness, as assessed by the Ishihara Color Test results (100% of their score was higher than the set threshold). They had no attentional disorders, too.

Subjects gave written informed consent in accordance with data laws (GDPR) and received a 15 euros compensation for their participation in the study.

In table 1, the main characteristics of the three participants' groups are reported in detail; additional information about their linguistic background are attached in the Annexes.

3.2.1.1 The two monolingual groups

Monolingual French speakers (N=23) were adults between 20 and 35 years (MEAN= 25.25, SD= 4.93), 29.17% were men and 70.83% of them were women; the educational background level of the group was quite uniform. In fact, 79.71% of them completed university studies, 37.50% of which obtained a bachelor's degree and 41.67% obtained a master's degree, whereas 20.83% of them accomplished college.

The mother tongue was French for all of them and most of them were born in France, with the exception of two participants, one born in Algeria and one in Cameroon; however, all of them (100%) lived in France at the moment of the experiment.

70.83% of them affirmed to speak English as a foreign language, and the 94.12% of them declared to be fluent, at different linguistic levels, in other foreign languages (mainly Spanish, Portuguese, German and Arabic). On the other hand, the remaining 29.17% did not speak any other languages.

Monolingual Italian speakers (N=22) had similar characteristics than French monolinguals. They were all adults between 25 and 33 years (MEAN= 29.65, SD= 2.16), 26.09% of them were men and 73.91% were women. The educational background level was slightly more heterogeneous than French participants: 20.24% accomplished college, 64.28% of them made university studies (10.71% obtained a bachelor's degree and 53.57% got a master's degree) and 15.48% had completed a PhD.

For 100% of them, their mother tongue was Italian and they were all born in Italy. 100% of them lived in Italy, in Rome and its surroundings, when they took part in the experiment. They all came from regions in central Italy; relevant differences in the light blue lexicon (*azzurro vs celeste*) were, thus, eliminated.

All of them studied English as a foreign language at school and for 83.33% of them English is their second language; whereas for the remaining 16.67% the second language is French or Spanish, whose linguistic proficiency does not exceed the intermediate level. For this reason, their knowledge of French does not have an influence on our experience. All of them affirmed to be fluent, at different linguistic levels, in at least another foreign language (50% in French and 50% in Spanish).

3.2.1.2 The bilingual group

The last group of participants was made of French-Italian proficient bilinguals: twentyone adults (N= 21) aged from 18 to 34 years (MEAN= 24.7, SD= 4.26), of which 85% were women and 15% were men, participated in the experiment. The educational background level of the bilingual group ranged from college (10%) to PhD (5%), with 20% who have accomplished a bachelor's degree and 65% who have obtained a master's degree.

They all lived in France when they took part in the experiment but 70% of them have spent more than 3 consecutive months in Italy in their life and 60% have lived in Italy for more than one year. 68% of them come from mixed families, where one parent is Italian and the other one is French and are considered early bilinguals for having grown up in a daily

bilingual linguistic environment (i.e., the age of acquisition of the second language is between 0-7 years old). The other remaining 32% are defined as late bilinguals since they learnt Italian after the age of 7 in a more formal, institutional environment. From a linguistic point of view, we tried to constitute a bilingual group the most homogeneous as possible: all the subjects had, in fact, an Italian proficiency level corresponding to a C1-C2 linguistic level, according to the CEFR; 65% of them are even considered as Italian native speakers. They are, thus, considered as French-Italian proficient bilinguals.

Moreover, they affirmed being all fluent in English, learned at school, and 94.74% of them also mastered a fourth foreign language, which was Spanish or German.

	French Monolinguals		Italian Monolinguals		French- Italian Bilinguals	
	MEAN(SD)	RANGE	MEAN(SD)	RANGE	MEAN(SD)	RANGE
Age						
	25.25 (4.93)	20-35	29.65 (2.16)	25-33	24.7 (4.26)	18-34
PERCENTAGE (%)			PERCENTAGE (%)		PERCENTAGE (%)	
Gender						
Women	70.83		73.91		85	
Men	29.17		26.09		15	
Educational Level						
College	20.83		20.24		10	
Bachelor	37.50		10.71		20	
Master	41.67		53.57		65	
PhD			15.48		5	
MEAN IN NUMBER (n)			MEAN IN NUMBER (n)		MEAN IN NUMBER (n)	
Foreign languages spoken	2.5		2.5		3.8	
YEARS (n)			YEARS (n)		YEARS (n)	
Age of L2 Acquisition	10.28		12.57		10.35 (L3)	

Table 1: Participants' main characteristics: French monolinguals, Italian monolinguals, French-Italian bilinguals are compared for the average age, gender, educational level,

number of foreign languages spoken and the age of acquisition of their L2 (L3 for bilingual speakers).

In the Annexes, we reported some additional authentic information about bilinguals' linguistic background that they declared in the online questionnaire (the identity of speakers is hidden and replaced by an ID of identification in order to anonymize personal data).

3.2.2 Data collection

The experiments started in December 2021 and finished in June 2022, for a total duration of about six months dedicated to collecting data.

We decided to test all the participants in the country of the language tested in order to avoid, or at least to limit, the influence and the interference of other languages in the linguistic environment. French speakers have, thus, been tested in France, all in Nanterre (Ile de France), while Italian speakers were tested in Italy, in Rome. Bilinguals have been tested in France, since French was their mother tongue, as well as their daily life most used language.

The experiments took place at the MoDyCo Laboratory (University of Paris Nanterre) experimental room for French and bilingual subjects, whereas Italian participants have been tested in Rome. In the two cases, the room was quiet and darkened and the viewing distance from the screen was 60 cm, subtending 2° of visual angle.

The two experiments have been conducted on standardized computer monitors using the color calibration wizard on the database www.easyrgb.com once identified the red–green–blue (RGB) values. The monitor used in France was an ACER XF240H LCD display of

24": the spatial resolution was 2160 x 1440 pixel, the refresh rate was 60 Hz, and the color depth was 8 bit per channel.

The monitor used in Italy was a Full View Full HD HUAWEI AD80HW Display 23.8": the spatial resolution was 1080p Full HD Pixels (2160 x 1440 pixel), the active signal resolution was 1920 x 1080 pixel and the refresh rate was 59,940 Hz. The color depth was 8 bits per channel.

For the two monitors, color rendering and gamma were corrected with a X-Rite i1Display Pro colorimeter (SKU X-Rite i1D3 - i1D3DC+OEM) in high resolution mode using an open-source display calibration software called DisplayCAL², powered by ArgyllCMS.

In order to ensure that the monitor output was proper and stable, the maximum luminance was at 80 cd/m² and the CIE 1931 chromaticity coordinates and luminance for the monitors' primaries were: R = 0.614, 0.356, 27.3; G = 0.286, 0.600, 60.1; B = 0.146, 0.070, 9.4.

The CIE-L*ab coordinates of the white-point were L* = 100, a* = -0.002, b* = -0.014 (Yxy 100 0.3127 0.329; average ΔE^*_{00} = 1.2; maximum ΔE^*_{00} = 2.42) and all the stimuli were presented on a uniform grey background whose CIE-L*ab coordinates were L* = 77.43, a* = 0.01, b* = -0.01, which was metameric to D65 with luminance of Y = 35 cd/m² (RGB gray balance average absolute weighted ΔC^*_{00} was calibrated at 0.25). More details about monitors' calibration parameters are added in Annexes.

² <https://displaycal.net/>

3.3 Behavioural Experimental Protocol

The behavioural protocol of the current study is composed of two main experiments: a Color Word Stroop Task and a Speeded Color Discrimination Task.

The three groups of participants were all tested individually in the two experiments, whose experimental protocol is the same, except for the language stimuli (French or Italian). However, bilingual speakers had some additional experimental blocks which will be explained in the next sections about tasks' procedure.

All subjects received the same instructions in their mother language; for the bilingual group we decided to give instructions in French and Italian: half of the participants received them in French (N= 10) and the other half in Italian (N=11).

The stimuli were presented using the version 2.0 of E-Prime software (Psychology Software Tools, Pittsburgh, PA) and the order of the experiments was counterbalanced between participants in each group. The global duration of the whole experiment was \cong 1 hour; it lasted about 75 minutes for bilingual participants since they had additional experimental blocks.

3.3.1 Experiment 1: the Color Word Stroop Task

3.3.1.1. The Present Study

Since 1935, the Stroop Task has been used by various scientific fields, like psychology, linguistics and neurosciences, to test different kinds of populations and to explore various research questions through several experimental variants. Its creator, John Ridley Stroop (Ridley Stroop 1935), programmed three experiments with five colours: red, green, brown, blue and purple. In the first one, participants read aloud a succession of colour words printed in coloured ink that either matched the colour word (e.g., GREEN printed in green ink: congruent condition), or mismatched the colour word (e.g., GREEN printed in blue: incongruent condition). In the second experiment, participants had to say aloud

the colour of the ink of the words presented (e.g., the word RED printed in purple ink: the correct answer is “purple”) and the colour of some coloured squares. In the third experiment, Stroop measured the time required to read or to name the items to examine whether the practice of these tasks influenced the answers of the participants.

The results showed an asymmetry between the processes of word-reading and the processes of colour-naming, with a strong interference of the reading processes in the colour naming. However, colours had not an impact on the word reading. This effect, or the increased time in colour naming in incongruent conditions became the well-known Stroop effect. In incongruent conditions, in fact, a conflict between the lexical item (the color word) and the chromatic perception (the color ink of the word) arises. As John Ridley Stroop showed, practice can reduce the magnitude of this effect, but the interference remains.

During the years, these experiments have evolved and changed, with sometimes the integration of neutral control items, but have always allowed researchers to examine different kinds of language and cognitive processes, like the automaticity of word reading, the speed of cognitive processing and the selective attention.

The Stroop Effect can be caused by the difference in relative processing time in reading words and naming colours (words are read faster than colours are named) and/or by the competition between the diverging color information and the written word which is a source of interference.

Moreover, cognitive executive control, a set of processes including selection, attention, resolution, task switching, conflict monitoring and inhibition, is at the center of this task. In fact, in incongruent conditions, the conflict created by the word and the colour requires increased cognitive control to be solved, leading to longer naming latencies. Resolving this word-colour competition demands highly cognitive processes, requiring the inhibition of the distracting information during the task: to correctly name the colour of the word, participants have to suppress the interference coming from the automatically written word, turning attention to the controlled colour naming process. Thus, a decreased magnitude of Stroop interference can be linked to a better inhibition and attentional process.

In addition, the Stroop Task allows to study facilitation effects, which is the convergence of the information coming from the written word and the visual colour in the congruent condition, leading to faster reaction times. Facilitation and interference are two opposite effects: the former is defined as the difference in response time between the congruent condition and the control condition, while the latter is the difference between the incongruent condition and the control condition.

The aim of the present study is to analyse the semantics of the blue colour in French and Italian, with a special regard to the Italian word *azzurro* which is being considered as the twelfth Italian basic colour term. Inspired by the study of Valdegamberi and Paggetti (Valdegamberi, Paggetti, and Menegaz 2015), we want to bring complementary results for the weak linguistic relativity theory, showing the influence of linguistic mechanisms on visual perception. In fact, naming the Italian word BLU, written in dark blue ink, should require faster RTs than naming the word BLU written in light blue ink, since it belongs to a different lexical category. Consequently, colour categorisation implies the participation of cognitive mechanisms which label colours with different lexical items.

By testing French and Italian monolingual groups we can demonstrate the presence of an empirical difference in colour naming and perception in French and Italian; whereas testing bilinguals will allow us to obtain measures of language interference and facilitation in both their first language (L1) and their second language (L2), as well as information about the bilingual advantage hypothesis, which has already been discussed in chapter 2. In fact, the Stroop task records language skills and cognitive control abilities, largely affected by bilingualism, since it shows the interference strength of reading processes on colour naming which, in turn, is an index of linguistic connections' strength.

3.3.1.2 Material and design

In this first experiment, each group of participants was tested in his native language, except for bilinguals who were tested either in their L1 and L2. Thus, we created three different experiments: one in French and one in Italian, with an additional third experiment for bilinguals where French and Italian stimuli were mixed.

The experimental protocol was the same for the three groups.

For the French experiment, words stimuli were the color words ROUGE, VERT, BLEU and JAUNE and neutral stimuli were the words TABLE, CHIEN, MAIN, PIED written in lowercase Times New Roman font; the corresponding ink colours were dark blue, red, yellow, light blue, dark green and light green. Thus, we had two shades of blue and two shades of green, but only two keys of the keyboard for each of them (dark and light green belong to the same colour category, as well as dark blue and light blue), for a total of four keys. The number of colours was restrained to six in order to limit the duration of the experiment.

The words' length (the number of syllables) was the same for colour words and neutral words, for which we chose words not conventionally based on a specific colour.

For the Italian experiment, we used the same experimental protocol as for the French one. The colour words stimuli were the words ROSSO, VERDE, BLU and GIALLO in lowercase font; neutral stimuli were the words SPALLA, GATTO, LIBRO and APE; ink colours were dark blue, red, light blue, light green and dark green and four response keys on the keyboard. Even for the Italian experiment the words' length was the same for colour words and neutral words, which were not conventionally based on a specific colour.

French and Italian color words have been chosen because of their basicness, which could show us an effect of incongruence when the Italian word BLU is written in light blue (corresponding to the BCT *azzurro*).

Moreover, the two greens have been chosen to be our control stimuli of the two blue hues: the expected differences in the reaction times between light and dark blue hues on the color word BLU can be caused by linguistic and/or cognitive mechanisms on perception. These differences should not be observed with dark and light green stimuli.

For ink colours, we adopted the sets of colours used by Paggetti and Menegaz in their previous studies (Paggetti, Bartoli, and Menegaz 2011; Paggetti and Menegaz 2013) whose sampling prototypes had coordinates based on the Munsell system: yellow= 5Y 9/12, red = 7.5R 5/20, dark green = 10GY 1/10, light green = 10GY 6/14, dark blue = 5PB 1/10, and light blue = 5PB 6/14. Light blue color and dark blue color had the same hue but different value, as well as light green color and dark green color.

Stimuli are all reported in Table 2.

	Color Words	Color Ink	Neutral Words
French	ROUGE, VERT, BLEU, JAUNE	Rouge, Jaune, Vert clair, Vert foncé, Bleu clair, Bleu foncé	TABLE, CHIEN, MAIN, PIED
Italian	ROSSO, VERDE, BLU, GIALLO	Rouge, Jaune, Vert clair, Vert foncé, Bleu clair, Bleu foncé	SPALLA, GATTO, LIBRO, APE
Bilingues - mixte block	ROSSO, VERDE, BLU, GIALLO, ROUGE, VERT, BLEU, JAUNE	Rouge, Bleu clair, Vert clair, Vert foncé, Bleu foncé	SPALLA, GATTO, LIBRO, APE, TABLE, CHIEN, MAIN, PIED

Table 2: Stroop Task Stimuli of the three groups of participants.

For the manual response, we maintained the number and the position of keys (d, f, j, k) always constant in all the experiment groups. In fact, for each experiment, we created two lists of participants to counterbalance the keys' order between participants: each colour, so each key, appeared with the same frequency in each position on the keyboard.

3.3.1.3 Procedure

Although at the present time there exists several linguistic and non-linguistics versions of the Stroop Test, the current study used the original linguistic version of the color word naming task.

Each experiment, the French, the Italian and the French-Italian mixed ones, was composed of a total of 3 blocks in the experimental session: each block was composed of 54 stimuli, for a total of 162 stimuli. Each block contained the same number of congruent, incongruent and neutral stimuli, presented in a random order, to avoid unbalanced distribution between blocks and participants. Thus, we had 18 congruent, 18 incongruent and 18 neutral stimuli in each block for each experiment.

All the participants conducted a brief practice session, made of 18 stimuli in total, to familiarize with the task and the correspondence between colours and the button keys. They were asked to respond manually, pressing one of the four keys on the keyboard (*d*, *f*, *j*, *k*) corresponding to the colours of the word appearing on the screen, ignoring its semantics. Participants used their two hands to answer: the right index finger for the *j* key, the right middle finger for *k*, the left index finger for *f* and the left middle finger for *d*.

Once the experiment began, subjects were instructed in their native language to keep their gaze fixated in the center of the screen and not to move. In each trial, a fixation cross appeared for 500 ms, then the word appeared in the middle of the screen. Stimuli remained on the screen until participants made a response; if no response was made in 3000 ms, the stimuli disappeared, and the next trial began. The rest time between the stimuli was 2 seconds, according to the distractor-suppression effect detected in the Stroop task (Neill and Westberry 1987) which persists for one second, but disappears after 2 seconds. This factor would avoid the post visual effects of the previous color word stimuli on the following one: selective attention, which inhibits some specific distractive information in the Stroop task, is an active time-dependent control process.

At the end of each block, or 54 trials, there was a pause until the subject decided to continue the experiment, pressing the key SPACE, in order to limit the impact of fatigue on the participants' performance.

The bilingual group passed three experiments in total: one in French, one in Italian and the last one with French and Italian mixed stimuli. The order of the two monolingual experiments was counterbalanced between participants: the half of them made before the L1 experiment and then the L2 experiment, and the other half inversely; the mixed experiment was always the last one. However, the correspondence between colours and the response keys on the keyboard changed for the three experiments in order to avoid familiarity and training effects. Each participant had to memorize a new color-key correspondence at the beginning of each experimental block.

This double experiment allowed us to analyse the possible cross-linguistic influences from L1 and L2 and inversely, as well as the inhibitory control and the facilitation effects, giving important information about the way bilinguals process and manage their two languages. Language interference can also give us relevant information about lexical representation of the double linguistic system and the strength of connections between languages in the mental lexicon. Attention, automaticity and cognitive control processes could confirm the hypothesis that the bilingual inhibitory control is better trained due to their double linguistic system use and switching in their everyday life.

In the bilingual mixed experiment, congruent, incongruent, and neutral conditions are presented in a single block made up of all three conditions, and in the two languages. Words in the bilinguals' first language (L1) or second language (L2) are presented in a random order: the color words were the same, either in French and Italian, as well as the color ink of stimuli.

We decided to add the mixed experiment since a single-language stimuli presentation may make the task too simple for bilingual participants and their responses may not be sufficient to elicit any differences between groups and languages. Therefore, the current

study used a more complex protocol with a more challenging task for participants, with an increased number of color terms in both their L1 and L2 mixed in a single block.

In Figure 28, an example of a trial of the Italian Stroop experiment is summarized with the three kinds of stimuli.

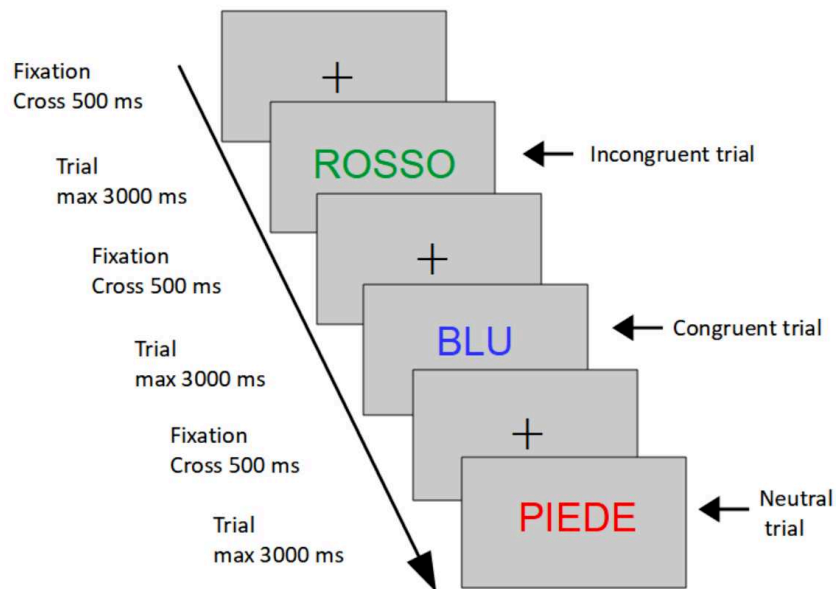


Figure 28: Stroop Trial event: in each block of trials, color word stimuli (congruent, incongruent and neutral) are interspersed with the appearance of a fixation cross on a grey page.

3.3.1.4 Hypothesis

The Color Word Stroop Task has allowed us to test the French and Italian color naming of visual chromatic stimuli, lexically labeled with the two color words *bleu* et *blu*. We indirectly analysed the status of BCT of the Italian color word *azzurro*, through the collection of RTs and the percentage of accuracy for congruent, incongruent and neutral word stimuli coloured of different color inks.

Our main hypothesis is based on the traditional Stroop effect: if Italian has two BCTs for the two different blue colours (*blu* and *azzurro*), the color word *blu* would be discriminated with faster RTs and higher accuracy when it is written in dark blue than when it is written in light blue from the Italian speakers. This distinction in accuracy and reaction time should be absent in the French speakers' group, since their language has only one basic blue color word (*bleu*) for the two hues.

For bilinguals, we suppose that they behave as the Italian speakers, or that they would be faster and more accurate when the color words *blu* and *bleu* are written in dark blue than when they are coloured in light blue. They would, thus, apply the Italian lexical distinction even to French stimuli, since the linguistic categorisation which made this distinction influences all kinds of perceptual tasks. In fact, the French word *bleu* written in light blue would represent for them a conflict as well as an incongruent stimulus where inhibitory mechanisms take place, differently from monolingual French participants.

Moreover, global slower times of response and an inferior degree of accuracy are expected for the bilingual group compared to the two corresponding monolingual groups.

To sum up, we pretend the presence of behavioural differences between the three groups for the Blue Color Word Stroop Effect (*bleu/blu* written in dark blue or in light blue): naming a dark blue color requires distinct RTs than naming a light blue color if they are both combined to the Italian color word *blu*. All the possibilities for the Blue Color Word Stroop Effect are: **Bleu** / **Bleu** / **Blu** / **Blu**.

However, a general Stroop Effect for which congruent stimuli (e.g., *vert* written in green ink) are more easily and rapidly distinguished than incongruent stimuli (e.g., *vert* written in yellow), is predicted for all participants.

3.3.2 Experiment 2: the Speeded Color Discrimination Task

3.3.2.1. The Present Study

The second study we conducted is a Speeded Colour Discrimination Task, inspired by the experiment of Winawer and his colleagues (Winawer et al. 2007) with some modifications in the experimental protocol. They studied the semantics of *blue* in English and Russian, focusing on the manners that these languages have to categorize the blue colour space linguistically. Cross-linguistic differences in colour perception rely on the debate concerning the way and the extent to which language shapes cognition and perception.

In fact, it seems that Russian makes an obligatory discrimination between light blue (*goluboy*) and dark blue (*siniy*), too. Winawer and his team tested English and Russian speakers in a perceptual task using stimuli covering the blue area borders, from *siniy* to *goluboy*. Participants were shown three squares simultaneously arranged in a triad and they had to say which of the two-colour squares on the bottom was perceptually identical to the square on the top.

This experimental protocol allows researchers to analyse whether language affects objective colour discrimination, investigating the way in which linguistic differences lead to differences in colour discrimination. Subjects were instructed to answer as quickly and accurately as possible and they made the experiment under three conditions: one with no interference, a second one with a spatial interference, in which subjects keep a spatial pattern in memory while completing colour discrimination trials, and a third one with a verbal condition. For this latter, we made some modifications compared to the Winawer's experimental protocol: we used the memorization of colour words instead of an eight-digit number series to rehearse during the colour task, following the model of the study conducted by Gilbert, Regier, Kay and Ivry (Gilbert et al. 2005).

The advantages of this design were multiple: firstly, it allows researchers to test the effects of language on colour perception in an objective task, answering to an unambiguous question, with no subjective judgment required. Linguistic representations are not used only for subjective judgments since the effects of language are clearly shown in an objective unambiguous task with a correct answer.

Secondly, the stimuli were presented simultaneously on the screen, resting in view until the participant's answer was made. This aspect gave the possibility to the subject to take his time and make his decision in the presence of the perceptual stimuli, with minimal memory demands.

Thirdly, Reaction Times are an implicit measure which cannot be controlled by participants since it is not modulated explicitly. Moreover, with the integration of interference blocks, with and without verbal distractors, we can analyse whether the cross-linguistic differences in colour discrimination depend on the online involvement of language during the task.

Winawer's results have been quite relevant since Russian speakers showed a Category Advantage (CA): they were faster and more accurate to discriminate two colours when they belonged to distinct linguistic categories in Russian than when they fell into the same color lexical category. This advantage disappeared during the verbal dual task, but it remained during the spatial dual task. Moreover, the effect was more intense when the colours were perceptually close (difficult discriminations) than when the colours were perceptually distant (easy discriminations). By contrast, English speakers did not exhibit a category advantage in any of the conditions.

Winawer's findings have been often criticized since different basic aspects have not been considered in their analysis (Martinovic, Paramei, and MacInnes 2020). Some of the most salient critics addressed to their work is about the possibility of a "categorical facilitation" (Christoph Witzel and Gegenfurtner 2015), rather than a real categorical perception effect, in the impact of categories on perceptual differences. In this case, the categorical advantage would emerge only at the color boundary. Moreover, it seems that the luminance of the background has not been considered by Winawer and his colleagues, whereas it represents a crucial factor of facilitation. As attested by the recent work of Martinovic and colleagues (Martinovic, Paramei, and MacInnes 2020), the difference between the luminance of the background and the luminance of color patches has an impact on RT performances. As a consequence, darker blue stimuli responses were slower than light blue stimuli responses since the latter were closer to the luminance background.

Furthermore, differences in color perception can be determined by cognitive factors, like attention, not only by linguistic categorisation. Cognition can, in fact, exert a direct top-down influence on perception, through an effect of modulation of the visual decisions, but only in tasks promoting categorisation. This aspect has not been considered by Winawer and his colleagues who explained the presumed effect they obtained as only driven by linguistic distinctions.

We are, thus, conscious of the limits of the Winawer's study; for this reason, we have considered in our methodological design all these additional factors they ignored in their experimental protocol.

Like English and Russian, it is assumed that French and Italian partition differently the colour spectrum in the bleu area, producing differences from a lexical and perceptual point of view.

According to Winawer's findings, we expect similar results for French and Italian with additional results coming from the bilingual group, which would have been essential to confirm and prove our thesis. The data obtained allowed us to analyse the cross-linguistic interference from one language to another and the way in which perceptual categories are affected by a double linguistic categorisation.

With the present research we can demonstrate that cross-linguistic differences in colour discrimination are influenced by the online involvement of language, as Winawer and his colleagues attested in their study. In fact, if a colour boundary is present in one language but is absent in another, like in Italian and in French, the speakers' outcomes of these two languages are supposed to differ in their perceptual discrimination across that boundary and the verbal interference affects only the language group that make this linguistic distinction, notably Italian monolinguals and French-Italian bilingual speakers.

For this reason, subjects performed the colour discrimination task under three conditions: only the verbal dual task should diminish or disrupt the *blu/azzurro* Italian category advantage; the non-linguistic dual task should conserve this advantage. Thus, we used the spatial-interference control condition to investigate whether the differences between the

control condition and the verbal-interference condition were specific to language functioning or they were caused by the type of task, in this case a dual task.

With the bilingual group we can study the language dominance and the inhibitory control, as well as the perceptual strategies depending on the language system used. In fact, bilinguals have to perform a perceptual task choosing, unconsciously, between two distinct systems with different categorizations, causing the emergence of a linguistic-cognitive conflict. Since one of their language systems makes the linguistic distinction in the blue boundary, do they adopt this system to perform an objective perceptual task, allowing the Italian linguistic colour categorization to predominate on the French one? Even though Italian is their L2, we expect that the L1 French colour perception is inhibited by the more powerful Italian discrimination; once a new distribution is acquired, subjects can't suppress it and apply it to any language's perception and non-linguistic behaviour.

3.3.2.2 Material and design

In this second experiment, the experimental protocol was the same for the three groups; all the participants of the Color Word Stroop Experiment also participated in the second experiment: the experimental order was counterbalanced between participants.

Each participant completed three trials blocks: one block of 136 colour discrimination trials without interference (the baseline block), one block while simultaneously performing a secondary verbal task (linguistic interference block, hereafter Verb Int Block) and a third block while performing a secondary spatial task (non-linguistic interference block, hereafter Spat Int Block). The blocks' order was counterbalanced between subjects to avoid any kind of bias due to regular patterns.

Colour stimuli were twenty color patches created with Photoshop for this study, ranging from light blue (*azzurro*) to dark blue (*blu*): we reproduced Winawer's study color stimuli whose Yxy coordinates of the Commission Internationale de l'Eclairage (CIE) ranged from

84, 0.214, 0.255 (stimulus 1, the lightest blue) to 5.3, 0.154, 0.09 (stimulus 20, the darkest blue). Starting from the two extreme color hues from light to dark blue, we created a set of 18 perceptually linearly equidistant color stimuli in order to obtain the 20 color stimuli, where $\Delta E=4.25$ for adjacent colours. Stimuli mainly differed in lightness and in chromaticity.

The uniform gray background was the same as the Color Word Stroop Task: it was metameric to D65, luminance was $Y=35\text{ cd/m}^2$, and the CIE-L*a*b coordinates were $L^*=77.43$, $a^*=0.01$, $b^*=-0.01$.

Each color square was 2.5 cm per side; the two color discrimination squares were 5.2° right or left from the vertical line, whereas the target color square was centered and placed 3.1° above the bottom pair.

Before starting the experiment, a short practice block was administered to participants: it was composed of 12 trials in all the three possible conditions. The grid and the colour words used for the practice were expressly created for this block, thus different from those present in the experimental blocks. The color trials belonged to the green spectrum to avoid the repetition of the experimental blue stimuli: we created 20 green colour patches ranging from light green (stimulus 1, corresponding to the Yxy coordinates 51.532, 0.36037, 0.4788) to dark green (stimulus 20, corresponding to the Yxy coordinates 3.515, 0.22957, 0.41464). The colour patches used for the practice block were randomly chosen, but they kept constant the Near/Far condition, (two steps apart in the continuum of 20 and four steps apart in the continuum of 20, respectively).

At the end of the experiment, subjects completed a post-experimental test of colour naming task to determine their individual blue colour boundaries. The same twenty colour stimuli covering the blue colour space, from light blue (*azzurro*) to dark blue (*blu*), used in the Speeded Color Discrimination Task were presented twice in random order. Participants were asked to classify each colour, with a key press (key *n* or *z* on the keyboard), saying if it belonged to dark or light blue (for French speakers) and if it was

part of *azzurro* or *blu* (for Italian and bilingual speakers). Each stimulus remained on the screen for a maximum of 2000 ms and a blank gray screen with a fixation cross followed each color stimulus for 500 ms before the emergence of a new color stimulus (Figure 29).

Subjects had to answer as quickly and perceptually instinctively as possible.

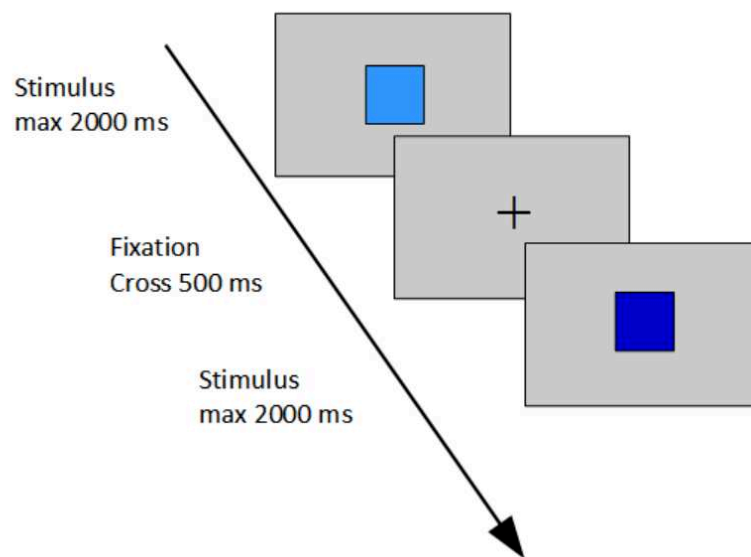


Figure 29: Trial event of the Color Boundaries post experimental test.

For each subject we identified the transition point in his/her classification responses, which represents the individual color boundary. If the transition was ambiguous or fell between two stimuli, we considered the slower reaction time to disambiguate the boundary since colours which are closest to boundaries tend to be categorized more slowly in this kind of simple classification tasks (Bornstein and Korda 1984). In some cases, disambiguation was particularly hard to solve since the transition point was not sharp enough: in these cases we used the 2AFC (two alternative forced choice) paradigm to detect the color boundary, defining the threshold with the stimuli categorized to 50% (C. Witzel and Gegenfurtner 2013; Hanley and Roberson 2011; Roberson, Hanley, and Pak 2009). The locations of the *blu/azzurro* boundary in Italian and bilingual speakers and the light blue/dark blue boundary for French speakers were similar: the color boundary falls

between stimulus 11 and stimulus 12 for Italian speakers (MEAN= 11.74, SD= 0,07), it falls between stimulus 12 and stimulus 13 for French speakers (MEAN= 12.56, SD= 0,10) and between patch 11 and patch 12 for bilingual speakers (MEAN= 11.23, SD= 0,09).

3.3.2.3 Procedure

The three groups of speakers performed the same experiment: as for the Color Word Stroop Task, each participant had an individual set of stimuli, randomly counterbalanced between subjects, submitted to some specific experimental constraints.

In each colour discrimination trial, subjects were shown three colour squares in a triad: one of the two squares of the bottom (the match and the distractor) was of the same colour of the square on the top (the target). The perceptual task was to say which of the bottom squares was physically identical to the top square; the answer was manual by pressing one a key on the left (Z) or a key on the right (N) on the keyboard.

The colour comparison was identified like a near-colour comparison or a far-colour comparison. In the first case, the distractor, or the non-matching colour square, was very similar to the other two (two steps apart in the continuum of 20 with $\Delta E= 8.50$); whereas in the second case, the distractor was more different to the other two squares (four steps apart in the continuum of 20 with $\Delta E=17$). Thus, colour discriminations can be either easier, when the target and the distracter colour squares were perceptually dissimilar, or harder, when the target and the distractor were perceptually closer.

This aspect helped us to analyse the way and the strength of the role of linguistic categories in perception, since they have a stronger influence on more difficult perceptual tasks (finer color discriminations) than on easy tasks.

Each color appeared equally often on the left and right in the triad and the same number of times as the match and the distractor square, as well as target stimulus.

Each participant of each group was submitted to three blocks of experience, one for each condition made up of 136 colour trials. The baseline block, or no-interference block, consisted of only colour discrimination task: each triad appeared at the centre of the screen and rested until participant did not answer. If no answer was done, the stimulus disappeared after 2000 ms. Then a fixation cross appeared for 1000 ms and the next triad appeared in the middle of the screen.

In the verbal interference block, participant was shown a single colour word to rehearse during the colour discrimination task. The word, presented for 2000 ms, drawn from the set: NERO, VERDE, ARGENTO, MARRONE, GRIGIO, ARANCIONE, ROSA, VIOLA, ROSSO, BIANCO e GIALLO for the Italian group, and NOIR, VERT, ARGENT, MARRON, GRIS, ORANGE, ROSE, VIOLET, ROUGE, BLANC and JAUNE for the French group. Thus, words' stimuli were presented in the participants native language, except for bilinguals whose verbal interference block was made of mixed stimuli in French and Italian: French and Italian colour words were randomly sorted by the set of 22 colour words, in equal proportion.

Subject had to rehearse the colour word while completing eight colour discrimination trials; after the 8 trials the recall was tested: a colour word was presented on the screen and the participant had to say if it was the same colour word shown before or not.

In the spatial interference block a 4x4 square grid was presented: four random squares were black, and subjects had to remember the pattern during the colour discrimination trials. Just like in the verbal interference block, the grid was shown for 2000 ms, followed by 8 trials, during which subjects had to maintain in their mind a picture of the grid. After the 8 trials, a two-choice test was given: a new grid was presented, and the subject had to say if it was the same grid shown before or not. The unmatched grids differed in the location of only one shaded square.

In the two interference blocks, 17 interference stimuli were used in each block and subjects had to press the SPACE key with both his/her thumbs when the second interference stimulus was the same as the previous one. In contrast, no answer was

required if the second stimulus was different. In the two interference blocks, 15% of the interference stimuli matched, for an average of 2,5 matched stimuli per participant. For the spatial interference, 14 different grids were created: 6 grids matched three times in each participants' group and 8 grids matched four times in each participants' group. The distribution of the matched grids was random and counterbalanced between participants.

In the Italian and French verbal interference blocks, each colour word matched four or five times in each participants' group: even in this case, the distribution was counterbalanced between participants and the definition of the colour words' matches was random. Otherwise, in the bilingual verbal interference blocks, all the colour words matched two times in the bilinguals' group, with the exception of six words (three Italian colour words and three French colour words) which matched four times. The distribution and the number of the match interference stimuli were counterbalanced between participants.

Each bilingual subject had, thus, at least one French word match and one Italian word match; participants having three matched words, can have two French words and one Italian word or inversely. Either the language distribution of the third match was controlled and counterbalanced between subjects.

The order of the 3 blocks (No-Interference Block, Verbal Interference Block and Spatial Interference Block) was counterbalanced between participants in each group to avoid bias.

Figure 30 reports an example of an experimental trial showing the three possible interference conditions.

NO INTERFERENCE / INTERFERENCE CONDITION

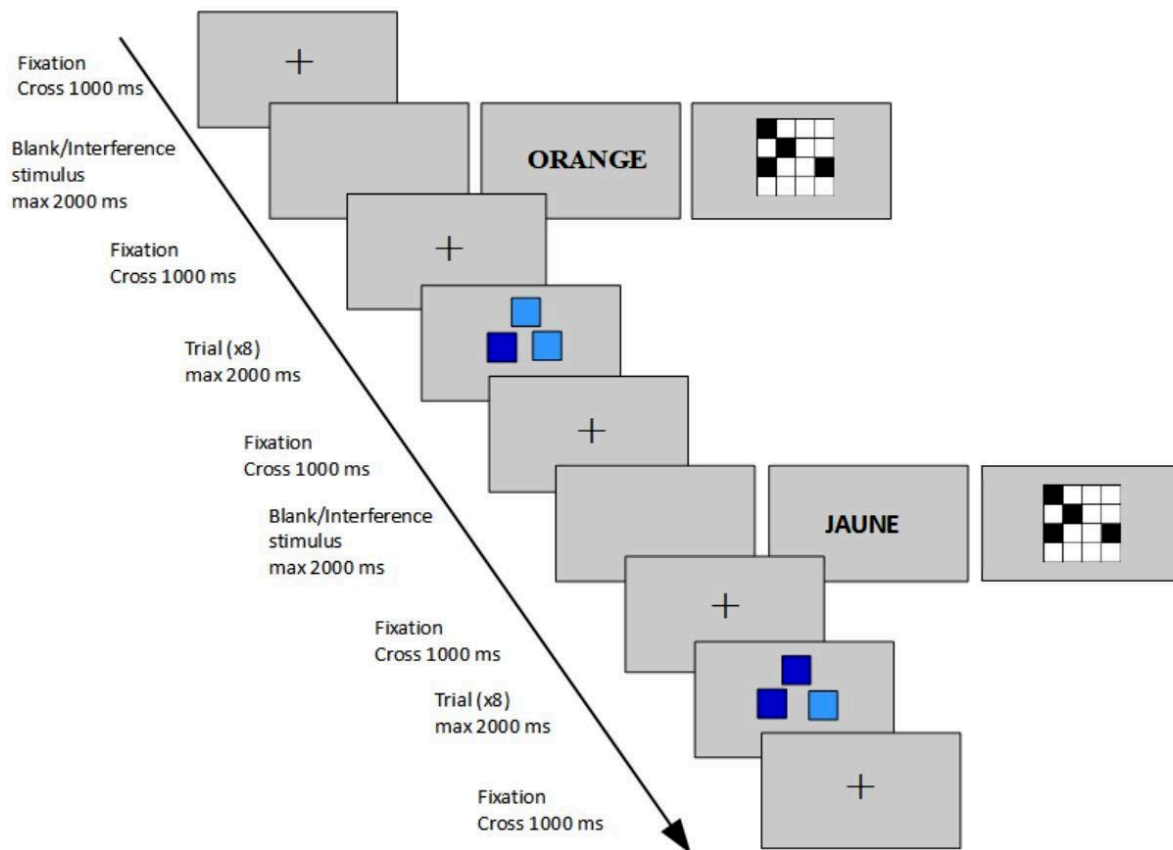


Figure 30: Trial event of the Speeded Color Discrimination Task with all the three possible interference conditions.

3.3.2.4 Hypothesis

Through the Speeded Color Discrimination Task, we can empirically analyse the hypothesis that *azzurro* represents a BCT in Italian with the distinction of two color categories distinguishing light blue hues from dark blue hues. Since the task is an objective perceptual task, where lexical and cognitive factors affect perception, we can also explore the degree of a direct impact of language on chromatic perception.

Our main hypothesis is the emergence of a category advantage (CA) in RTs and accuracy either in the No-interference experimental block and in the Spatial interference block in

Italian monolingual speakers. This CA would disappear in the verbal Interference block because of the effect of lexical rehearsals during the perceptual task, showing a direct effect of language processing on color perception. Moreover, this category advantage would be stronger for near color discriminations than for far color discriminations, since they represent more perceptually difficult distinctions.

However, we expect that the category advantage would not emerge in the French group in any experimental block, due to the lack of two different lexical blue categories.

For the bilingual group, we presume that they behave like the Italian monolingual, showing a CA in the No-interference block and in the Spatial interference block, but not in the Verbal interference Block. These results would be explained by the theory assuming that, once the bilingual mind has interiorized a new conceptual system, it adopts its cognitive distinctions even in completely perceptual tasks or in tasks involving another linguistic system with a different categorisation. In our study, French-Italian bilingual speakers would use the categorical system of the language owing a lexical distinction (Italian), which is not their native language, even for the distinction of chromatic stimuli considered perceptually universal. This aspect would rely on the hypothesis of a bilingual advantage, too.

More generally, language, accompanied by cognitive functions, like attention, memory and discrimination judgments, has, thus, a top-down influence on perception, especially in color perception.

Conclusions

In this chapter we presented the topic of our research project, as well as the experimental study we implemented and put into practice to explore it.

We reported in detail our research thesis accompanied by the objectives and the general hypothesis of our study, which aims to bring additional empirical evidence about the Italian word *azzurro* as a BCT defining a basic color category (BCC), as well as to demonstrate the impact of lexical and cognitive categories on perceptual mechanisms.

In a second time, the experimental protocol, composed by two main experiments (a Color Word Stroop Task and a Speed Color Discrimination Task), has been detailed: from groups' characteristics to data collection. Each experiment has been described based on the models which have inspired us: methods, procedure, design and hypothesis have been rigorously presented for future possible reproductions.

The next chapter is dedicated to the data analysis and the results coming from our experiments, which will be discussed and compared to our initial hypothesis. The limits of our research, as well as future perspectives will occupy the second part of the next section, which will end with some general global conclusions.

PART IV: Results and Future Research Directions

Chapter 4: Results and Discussion

Introduction

This chapter aims to show the data analysis of the two experiments conducted with monolingual and bilingual speakers. In the first section we will present all the obtained results per group: for each experiment we will detail, for each group of participants, the behavioural analysis we made, as well as the discussion of subjects' outcomes and performance. Then, we will explain the comparative analysis we conducted, through both between-subjects comparisons and within-subjects comparisons, in order to evaluate the statically significance, or not, of the reported differences.

Common tendencies and groups' discrepancies will be discussed in the second part, where we consider the possible congruency between our results and the expected effects. We will validate or not our initial hypotheses, too.

Some general conclusions about results and data interpretation will close the chapter.

4.1 Results

Data analysis and results are reported for each experiment. We firstly discuss the Color Word Stroop Task statistics for French monolinguals, Italian monolinguals and French-Italian bilinguals, which will be followed by the presentation and discussion of the Speeded Color Discrimination Task data.

4.1.1 The Color Word Stroop Task

In this section we detailed the Color Word Stroop Task results for each group of speakers, analysing two effects: the traditional Stroop Effect and the Color Word Effect, determined

by the differences linked to the light blue or dark blue ink of the two color words *bleu* et *blu*.

We will start with the discussion of the monolingual groups' results, which are followed by the bilingual data. Within-subjects factors and between-subjects factors analyses are conducted.

For each group of participants, we recorded accuracy (ACC) and reaction times (RTs) and analyses of standard errors (SE) were performed. Response time was defined as the interval between the onset of the stimulus and the participant response manually made on the keyboard. Time-out was calculated on two standard deviations from the mean of each participant; if the subject responded before or after the threshold values, the response was considered as missing. We averaged the RTs for correct responses in all the experimental conditions across participants.

Data outliers, with implausibly long or short RTs, were removed from our data set, too.

We conducted several different repeated-measures ANOVA analyses to examine errors and response times.

4.1.1.1 The Stroop Effect Results

The Stroop Effect is defined as the delay in reaction times between incongruent and congruent stimuli: for incongruent stimuli, where the color word and the color ink do not match, it takes longer and less accurate responses than for congruent ones.

We obtained a classic Stroop Effect for all our speakers' groups, both in within-groups comparisons and in between-groups comparisons. The Stroop Effect is determined by the variable of condition (congruent, incongruent or neutral).

4.1.1.1.1 The Monolingual Speakers

4.1.1.1.1.1 The French Subjects

a. Behavioural Analysis

In the French monolingual group, we excluded all the incorrect responses (5.5%) as well as all the outliers (3% of correct trials).

ANOVA results showed a Condition (congruent, incongruent, neutral) effect ($p < .001$) where RTs for congruent stimuli were faster than RTs for incongruent (MEAN = 721.321 ms, SD = 129.812 ms) and RTs for neutral stimuli (MEAN = 746.662 ms, SD = 161.580 ms) which, in turn, were more rapid compared to incongruent trials (MEAN = 818.792 ms, SD = 169.026 ms). Error analyses brought the same evidence: French monolingual speakers were more accurate for matching congruent stimuli (MEAN = 95.751%, SD = 10.503%) compared to incongruent (MEAN = 90.579%, SD = 12.392%) and neutral stimuli (MEAN = 95.401%, SD = 11.557%).

b. Discussion

The French monolingual within-subjects statistical analysis attested the presence of a strong Stroop Effect which demonstrated that, when a color word is printed in the same color as its semantics, naming the word ink color is easier and faster. Processes like selective attention, inhibition and reading automaticity, play a central role in this kind of perceptual task, revealing that the recognition of a color requires more cognitive factors than the word encoding.

4.1.1.1.1.2 The Italian Subjects

a. Behavioural Analysis

In the Italian monolingual group, we excluded all the incorrect responses (4.2%) as well as all the outliers (2.7% of correct trials).

As for the French group, behavioural results showed a Condition effect ($p < .001$) where RTs for congruent stimuli (MEAN = 726.989 ms, SD = 153.316 ms) were faster than RTs for incongruent (MEAN = 836.880 ms, SD = 206.377 ms) and RTs for neutral stimuli (MEAN = 738.420 ms, SD = 137.542 ms) always more rapid than incongruent trials. The accuracy analyses were more accurate for matching congruent stimuli (MEAN = 97.054%, SD = 3.987%) compared to incongruent (MEAN = 94.866%, SD = 6.388%) and neutral stimuli (MEAN = 96.633%, SD = 4.067%).

b. Discussion

Data results of the Italian within-group analysis have attested the statistical presence of the Stroop Effect even for Italian stimuli. This phenomenon, due to linguistic and cognitive processes, confirms the previous experimental findings on executive functions, especially on semantic interference and processing speed.

4.1.1.1.1.3 French-Italian Between-Subjects Comparison

a. Behavioural Analysis

For the first between-subjects comparison, we study the interaction between the two groups of monolingual speakers: we subjected the results of errors and response times to a two-way repeated measures analysis of variance (ANOVA C3 X G2) in which Condition (C), made up of three levels (congruent, incongruent, neutral) was considered a within-subjects factor, and Group (G), made up of two levels (French and Italian) was considered a between-subjects factor.

The obtained results showed a normal Stroop Effect where the condition variable is statistically significant ($p < .001$) for reaction times: $F(2, 84) = 28.930$, $MSE = 134663.519$, $p < .001$, $\eta^2 = 0.076$. We, thus, performed a post hoc exploratory analysis of RT distributions: the two groups globally responded faster for congruent stimuli compared to incongruent stimuli ($p^{\text{holm}} < .001$) with a mean difference of -103.681 ms. At the same

time, neutral stimuli RTs were faster than incongruent stimuli of about 85.296 ms ($p^{\text{holm}} < .001$).

However, we have not registered any interaction between Condition and Group, as we can see in Figure 31: RTs for congruent, incongruent et neutral stimuli are similar for the two groups of speakers, with the incongruent trials having the slowest reaction times either in French and Italian.

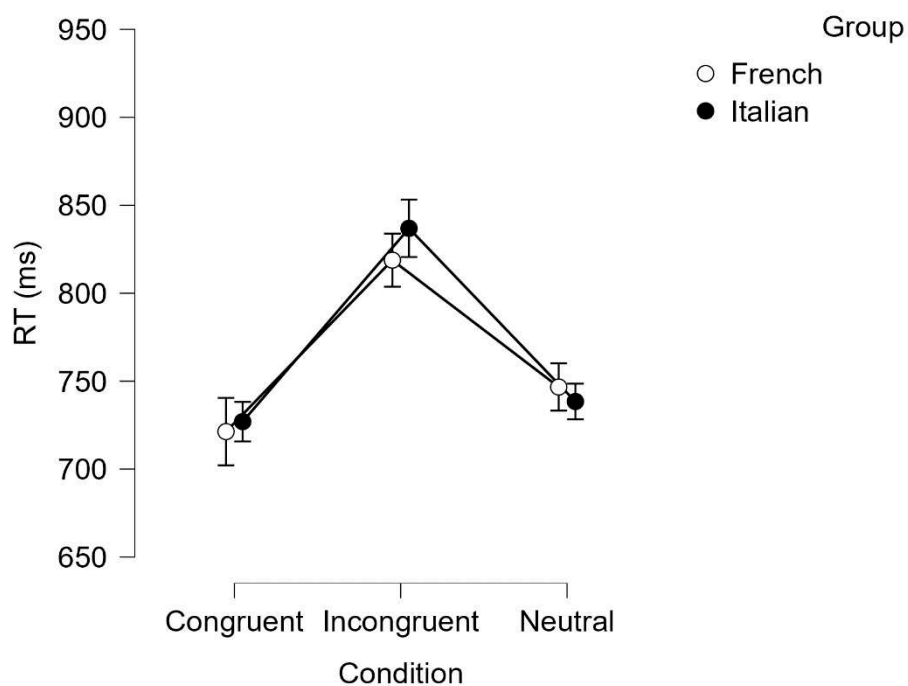


Figure 31: Reaction Times in milliseconds for the two monolingual groups (French and Italian) in the three stimuli conditions with Standard Error (SE) bars.

The accuracy analysis presented similar results: the statistically significant effect of condition ($F(2, 84) = 7.524$, $MSE = 180.002$, $p < .001$, $\eta^2 = 0.034$) showed, in a Post Hoc comparison test, that performances for congruent stimuli are globally more accurate than those for incongruent stimuli ($p^{\text{holm}} = 0.002$, $MD = 3.680\%$). At the same time, incongruent trials are more subjected to errors than neutral stimuli ($p^{\text{holm}} = 0.004$, $MD = -3.295\%$).

Moreover, even though we did not obtain any statistically relevant effect of interaction between Condition and Group, Italian speakers are globally a little more accurate than French locutors (MD = 2.274%), as illustrated in Figure 32.

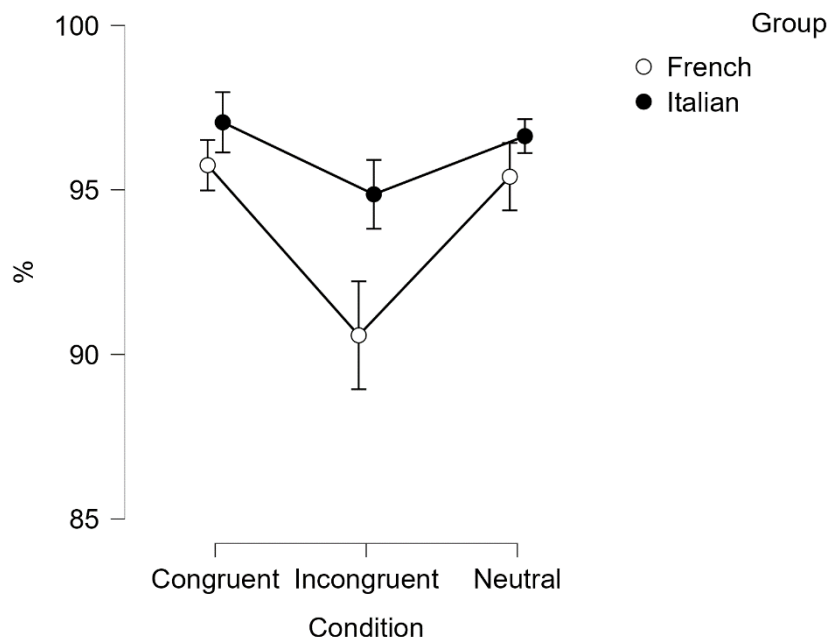


Figure 32: Mean Accuracy in percentage (%) for the two monolingual groups (French and Italian) in the three stimuli conditions with Standard Error bars.

b. Discussion

The first between-subjects comparative measure concerns monolingual performances for examining the way in which native speakers of the two languages perceive the two different shades of blue and how they categorize and express them lexically. During this stage we can identify the language resources used in a perceptive task, as well as their impact on color perception: similarities and contrast aspects will validate, or not, our initial hypotheses.

The ANOVA analysis has attested the presence of a statistically significant effect of condition in the French-Italian comparison. As a result, the two language systems behave

linguistically and perceptually in the same way, without any relevant distinctions between the two groups: color naming of color hues used in our experiment are faster and better processed when the color word is printed in the same color it refers to, independently of differences in lightness (dark or light).

4.1.1.1.2 The French-Italian Bilingual Speakers

a. Behavioural Analysis

In the Italian-French proficient bilingual group, we eliminated all the incorrect responses (4%) as well as the outliers for each participant (3.7% of correct trials).

We remember that bilingual speakers performed the Color Word Stroop Task three times: once in Italian, once in French and once in a French-Italian mixed experiment. The order of the Italian and French monolingual experiments was counterbalanced between participants whereas the mixed test was always performed at the end.

We performed repeated-measures ANOVA for within-subjects' comparisons, where Experimental Block (French, Italian, Mixte) and Condition (Congruent, Incongruent and Neutral) are considered repeated measures factors. This way, we compared results from the three experiments in order to identify distinctions in how the bilingual mind manages two linguistic systems, where lexical categorical discriminations can have an impact on color naming.

ANOVA RTs results showed two significant effects: one due to the experimental block ($p = 0.004$) and one determined by condition ($p < .001$). For the experimental block effect ($F(2, 40) = 6.338$, $MSE = 20685.758$, $p = 0.004$, $\eta^2 = 0.118$), we performed Post Hoc exploratory analysis for RTs which exhibited reaction times distributions: bilinguals are slower in the French experimental block compared to the mixed block ($p^{\text{holm}} = 0.006$, $MD = 84.778$ ms) as well as in the Italian experimental block compared to the mixed block ($p^{\text{holm}} = 0.016$, $MD = 71.599$ ms).

We made a Post Hoc test for the condition effect, too ($F(2, 40) = 55.295$, $MSE = 4518.283$, $p < .001$, $\eta^2 = 0.225$). Bilingual speakers are globally faster both in naming congruent stimuli compared to incongruent stimuli ($p^{\text{holm}} < .001$, $MD = -124.711$ ms) and in naming congruent stimuli compared to neutral stimuli ($p^{\text{holm}} < .001$, $MD = -47.111$ ms); their RTs are also slower for incongruent stimuli compared to neutral stimuli ($p^{\text{holm}} < .001$, $MD = 77.600$ ms).

Descriptive statistics gave us the details about the reaction times in each experiment for congruent, incongruent and neutral stimuli, as reported in Table 3 where MEAN and SD of each experimental block are reported for the three conditions.

Descriptives

Experimental Block	Condition	Mean	SD	N
French	Congruent	827.639	142.397	21
	Incongruent	981.687	217.251	21
	Neutral	875.071	145.101	21
Italian	Congruent	820.489	128.429	21
	Incongruent	954.224	173.939	21
	Neutral	870.148	159.632	21
Mixte	Congruent	766.490	102.832	21
	Incongruent	852.842	133.426	21
	Neutral	810.733	130.164	21

Table 3: Mean Reaction Time and Standard Deviation (in ms) for the three conditions in the three experiments (French, Italian and Mixte) performed by bilinguals.

All these results are summarized in Figure 33.

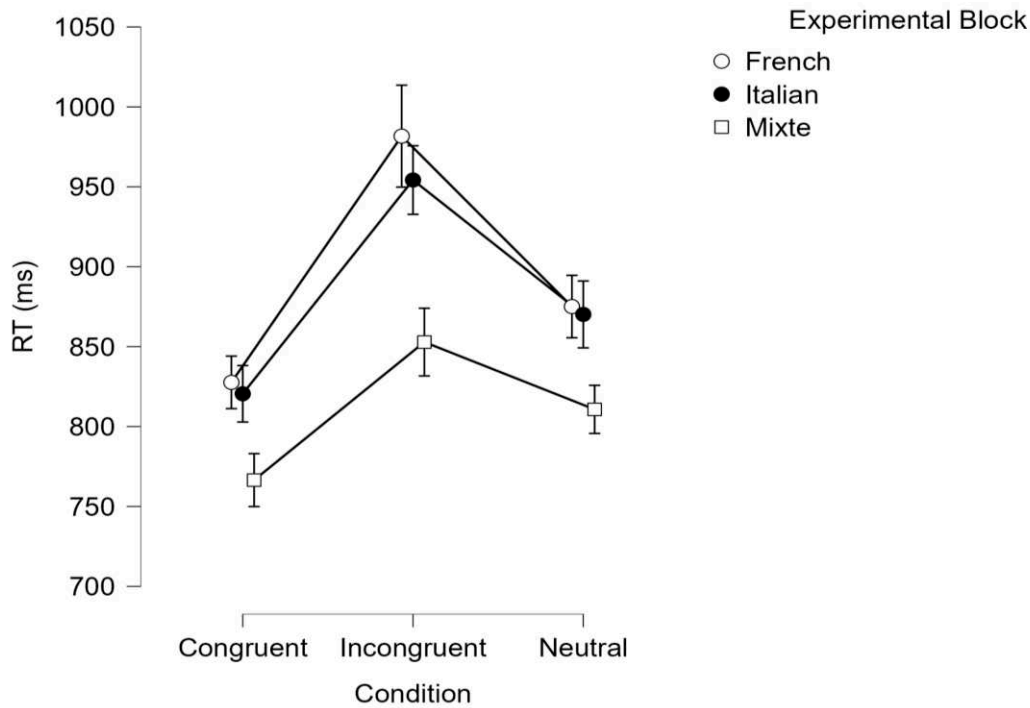


Figure 33: Reaction Times in milliseconds for the three bilingual experimental blocks (French, Italian and Mixte) in the three stimuli conditions with Standard Error (SE) bars.

We obtained an effect of condition also from ANOVA errors analysis ($F(2, 40) = 9.052$, $MSE = 11.061$, $p < .001$, $\eta^2 = 0.010$). Post Hoc exploratory accuracy distributions attested more precision in color naming responses for congruent stimuli compared to incongruent stimuli ($p^{\text{holm}} = 0.004$, $MD = 1.937\%$), as well as for neutral stimuli compared to incongruent ones ($p^{\text{holm}} < .001$, $MD = 2.366\%$).

Moreover, a tendency between Experimental Block and Condition ($p = 0.066$) has been identified, notably for congruent stimuli vs incongruent stimuli in the French experiment ($p^{\text{holm}} = 0.057$, $MD = 3.004\%$), incongruent stimuli vs neutral stimuli always in the French experiment ($p^{\text{holm}} = 0.008$, $MD = -3.543\%$) and for incongruent stimuli vs neutral stimuli in the Italian experiment ($p^{\text{holm}} = 0.057$, $MD = -3.005\%$).

In Figure 34, which reports the accuracy level for the three experimental blocks in the three stimuli conditions, the precision in responses in the mixed block is quite evident. This phenomenon will be discussed in the next section.

Meanwhile, in Table 4 the degree of accuracy (MEAN and SD) for the three experiment blocks are detailed: bilinguals are globally 6.422% less accurate in the mixed block compared to the two other experimental blocks.

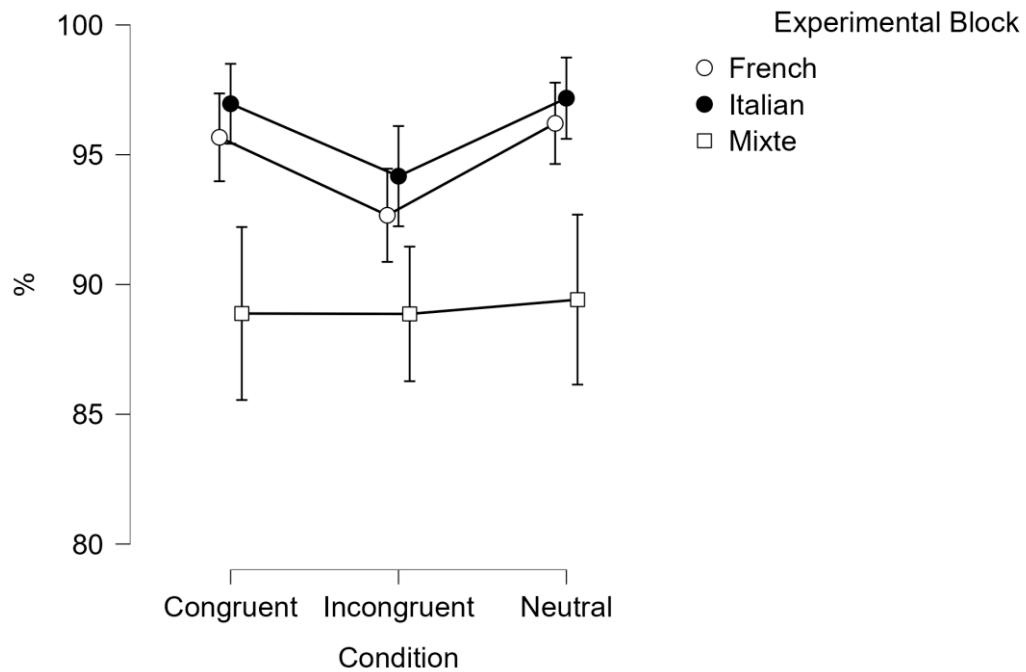


Figure 34: Accuracy analysis in percentage (%) for the three bilingual experimental blocks (French, Italian and mixte) in the three stimuli conditions with Standard Error (SE) bars.

Descriptive Statistics

	ACC_French Block	ACC_Italian Block	ACC_Mixte Block
Valid	21	21	21
Missing	0	0	0
Mean	94.848	96.106	89.055
Std. Deviation	3.842	3.715	19.574
Minimum	87.037	84.567	36.753
Maximum	99.383	100.000	100.000

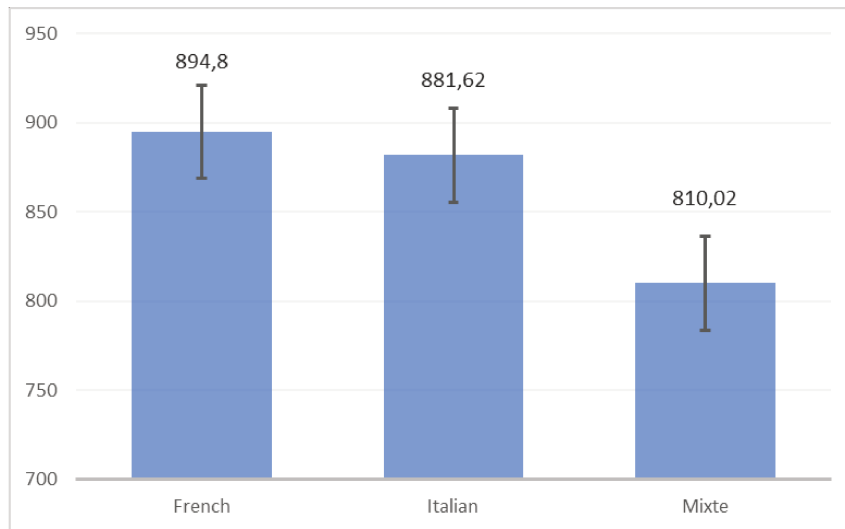
Table 4: Mean Accuracy and Standard Deviation (in %), with minimum and maximum values, for the three experiments (French, Italian and Mixte) performed by bilinguals.

b. Discussion

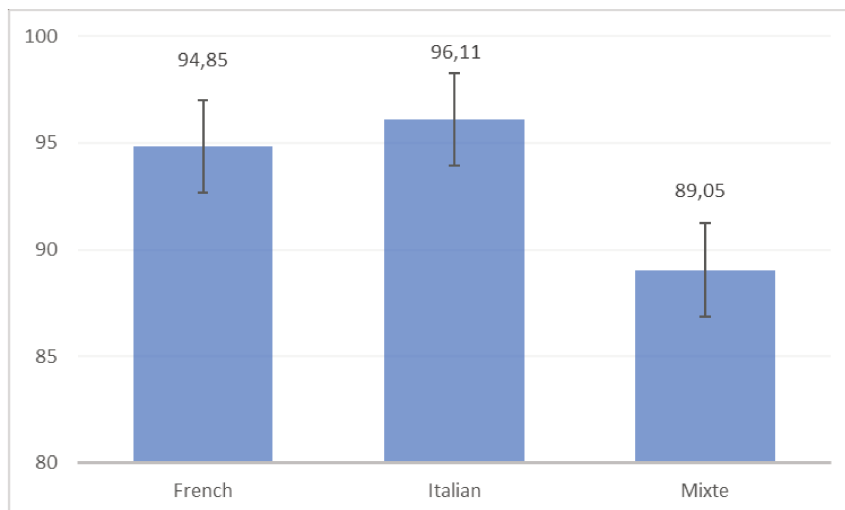
The within-subjects bilingual analysis has validated the thesis of a Stroop Effect in experiments performed in different languages both in L1 (first language) and in L2 (second language). We can attest that proficient French-Italian bilinguals behave in the same way when they are asked to name colours of French and Italian color word stimuli, as the corresponding monolingual groups. This factor tells us that they use the same cognitive mechanisms, as well as the same lexical categorization since stimuli in the two linguistic systems are equally processed. Therefore, they probably have interiorized the Italian linguistic distinction for the blue area adopting it for French blue stimuli too. If this would not be the case, French incongruent blue stimuli would be processed more rapidly than the corresponding Italian ones.

This study has allowed us to test the presence of eventual cross-linguistic interference from L1 to L2 and/or conversely, as well as the perceptive behaviour of speakers mastering two language systems.

Familiarity with the task and training effects can explain the results coming from the mixte block, which is always the third one to be performed (Graph 1 and Graph 2). Faster reaction times and better performances (inferior error rates) can, in fact, be due to repetition, even though it represents the most complex experimental block where cognitive conflicts and semantic inhibition are particularly elicited.



Graph 1: Stroop Effect's global mean reaction time (in milliseconds) for the three experimental blocks (with French stimuli, with Italian stimuli and with mixed French and Italian stimuli) performed by bilinguals with Standard Error (SE) bars.



Graph 2: Stroop Effect's global mean Accuracy performance (in percentage) for the three experimental blocks (with French stimuli, with Italian stimuli and with mixed French and Italian stimuli) performed by bilinguals with Standard Error (SE) bars.

4.1.1.1.2.1 French vs Bilingual Subjects Comparison

a. Behavioural Analysis

Another between-group comparison we made is the contrastive analysis between the French monolinguals and the French-Italian bilinguals L1 (French) whose purpose was to verify the eventual impact of the second language (in our case Italian) in the monolingual dominant language task.

For reaction times, repeated-measures ANOVA (C3 X G2) in which Condition (C), made up of three levels (congruent, incongruent, neutral) was considered a within-subjects factor, and Group (G), composed by French monolingual speakers and bilingual speakers tested in the French block (hereafter Bil.French), was the between-subject factor, have revealed a relevant effect of condition, corresponding to the classical Stroop Effect.

We performed a Post Hoc test to explore RTs distributions of this effect ($F(2, 82) = 31.249$, $MSE = 179978.830$, $p < .001$, $\eta^2 = 0.085$). As shown in figure 36, for the two groups, congruent stimuli are named more rapidly than incongruent stimuli ($p^{\text{holm}} < .001$, $MD = -125.759$ ms), as well as 36.387 ms faster than neutral stimuli ($p^{\text{holm}} = 0.029$). At the same time, incongruent stimuli are globally processed more slowly of about 89.373 ms ($p^{\text{holm}} < .001$) than neutral stimuli.

Furthermore, a group effect has been detected, too ($F(1, 41) = 8.290$, $MSE = 68302.957$, $p = 0.006$, $\eta^2 = 0.134$). The Post Hoc analysis has shown that bilinguals performing the French experimental block are globally slower than the corresponding French monolingual group ($p^{\text{holm}} = 0.006$, $MD = 132.541$ ms).

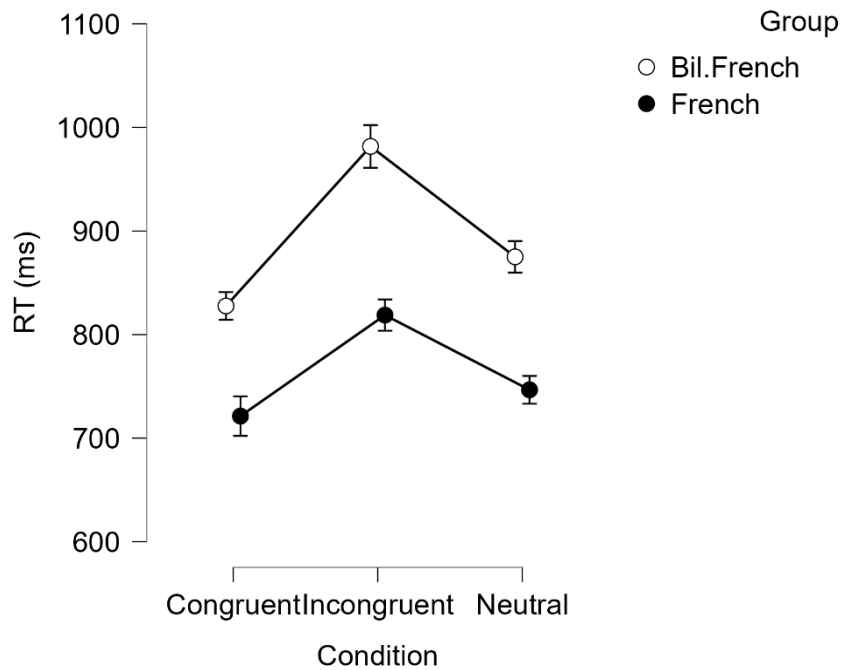


Figure 35: Reaction Times in milliseconds for the French monolingual group and the bilingual group in the French experiment in the three stimuli conditions with Standard Error (SE) bars.

For analysis of error rates, we registered only a condition effect ($F(2, 82) = 11.518$, $MSE = 245.037$, $p < .001$, $\eta^2 = 0.048$), validating the presence of a Stroop Effect. Post Hoc test has confirmed, from a statistical point of view, that naming the color of congruent stimuli lead to inferior error rates than naming the color of incongruent stimuli ($p^{\text{holm}} < .001$, $MD = 4.088\%$), which, in turn, are named with less accuracy than neutral stimuli ($p^{\text{holm}} < .001$, $MD = -4.182\%$). In Figure 36, we report all these results about error analysis, where we can graphically see the bilingual group being globally more accurate in the French experiment compared to the corresponding French monolingual group.

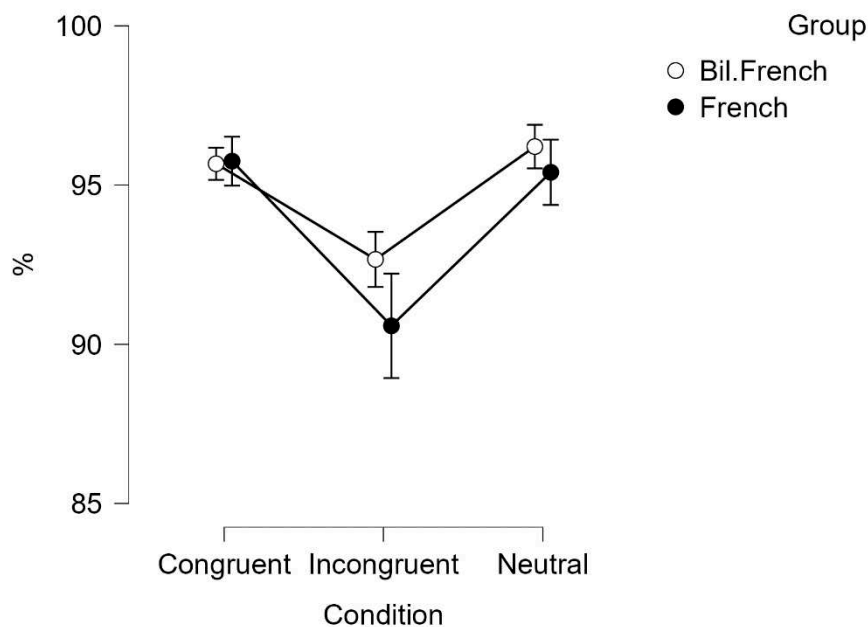


Figure 36: Accuracy performances in percentage (%) for the French monolingual group and the bilingual group in the French experiment in the three stimuli conditions with Standard Error (SE) bars.

b. Discussion

In the comparison between French monolinguals and French-Italian bilinguals in the French experimental block, we obtained statistically significant results, especially for the emergence of a strong Stroop Effect. Bilingual cognitive costs, linked to the constant inhibition of the offline linguistic system can explain this factor, as well as the possible hesitation provoked by the differences in categorization which can cause cognitive conflicts in performing a perceptual task.

However, if bilinguals are globally slower than the corresponding monolinguals, they are as accurate as French speakers (Gollan, Montoya and Werner 2002). The discrepancy between the two groups disappears in error rate.

4.1.1.1.2.2 Italian vs Bilingual Subjects Comparison

a. Behavioural Analysis

The last contrastive between-groups analysis we conducted for the Stroop Effect involves the group of Italian native speakers and the bilingual group tested in their L2 (Italian). Since bilinguals are highly proficient in Italian, we can predict that their outcomes are similar to the native speakers, but a form of interference coming from their L1 could appear.

For reaction time and accuracy statistical analyses, we obtained similar results than those from the between-subject comparison of French monolinguals and bilinguals in the French experiment.

In fact, repeated-measures ANOVA (C3 X G2) for reaction times have reported a significant effect of condition ($F(2, 82) = 38.072$, $MSE = 172632.275$, $p < .001$, $\eta^2 = 0.086$), or an expected Stroop Effect, as well as a group effect ($F(1, 41) = 6.029$, $MSE = 69710.177$, $p = 0.018$, $\eta^2 = 0.105$).

The Post Hoc tests we performed for RTs distributions showed that, even in this two groups' comparison, color naming of congruent stimuli is processed more rapidly than the color ink of incongruent stimuli ($p^{\text{holm}} < .001$, $MD = -121.813$ ms) as well as more rapidly than neutral stimuli ($p^{\text{holm}} = 0.039$, $MD = -30.545$ ms). Incongruent stimuli are, in contrast, named 91.268 ms more slowly than neutral stimuli ($p^{\text{holm}} < .001$).

The Post Hoc analysis for the group effect has displayed that bilinguals performing the Italian experiment are globally 114.191 ms slower than the Italian monolingual native speakers ($p^{\text{holm}} = 0.018$).

Similarly, statistical analysis of error rates attested the presence of the Stroop Effect with a significant effect of condition ($F(2, 82) = 6.619$, $MSE = 85.259$, $p = 0.002$, $\eta^2 = 0.058$). We performed another Post Hoc test which confirmed that congruent stimuli are named more accurately than incongruent stimuli ($p^{\text{holm}} = 0.006$, $MD = 2.489\%$) whose performances are less correct than those for neutral stimuli ($p^{\text{holm}} = 0.006$, $MD = -2.387\%$).

Statistical results for RTs are summarized in Figure 37, whereas accuracy statistical data are illustrated in Figure 38, where the descriptive plots of the two groups almost overlap.

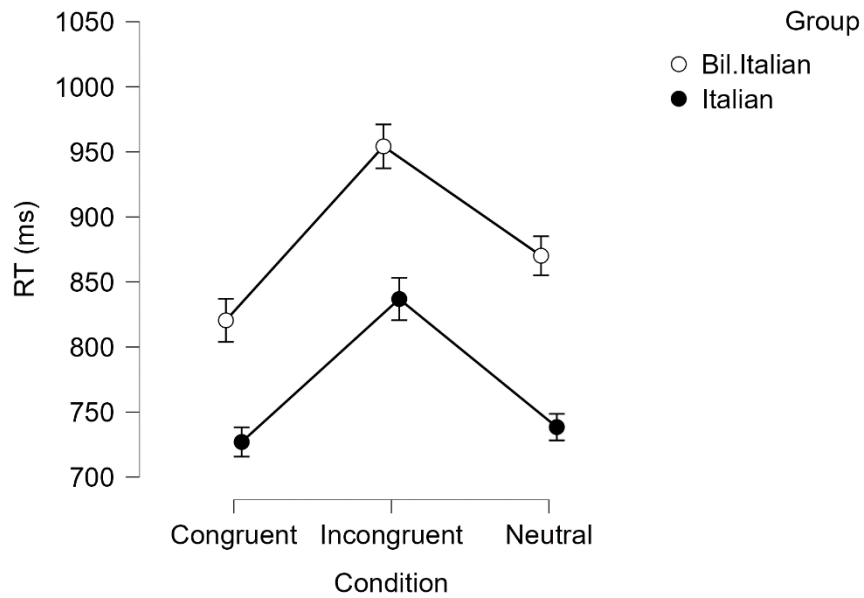


Figure 37: Reaction Times in milliseconds for the Italian monolingual group and the bilingual group in the Italian experiment in the three stimuli conditions with Standard Error (SE) bars.

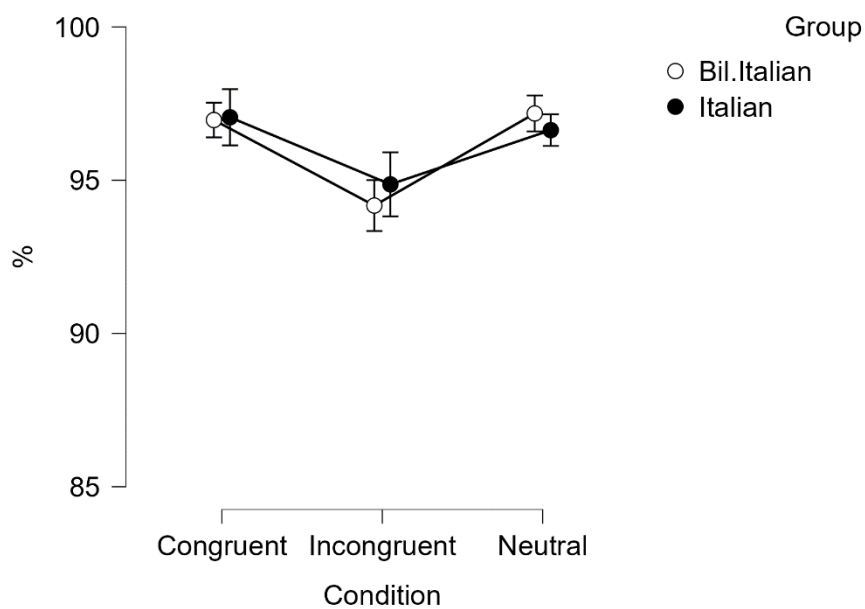


Figure 38: Accuracy in percentage (%) for the Italian monolingual group and the bilingual group in the L2 Italian experiment in the three stimuli conditions with Standard Error (SE) bars.

b. Discussion

In the comparison analysis between Italian monolingual speakers and bilinguals performing a Stroop Experiment in their second language (Italian) we obtained a significant global Stroop Effect for reaction times and accuracy. However, a relevant discrepancy in groups' RTs has been identified: bilinguals are considerably slower than monolinguals, as in the comparison between French monolinguals and bilinguals performing the French Stroop experiment.

This phenomenon can be explained by the cognitive costs due to conflicts and inhibitory controls always active in the bilingual mind.

In contrast, they had equal accurate performances than the Italian monolinguals, which means that the bilingual second language conceptual system has been fully interiorized. The overlapping of the error rates plots shows that proficient bilinguals perceptually behave as native speakers of Italian, taping to its lexical categorization structure.

4.1.1.2 Results for the Blue Color Word Effect

The second effect we explored from the Color Word Stroop Test data is what we called the Blue Color Word Effect, which refers to the differences in reaction times and error rate only for blue stimuli.

Blue Color Word Stroop Effect, or the two words *bleu* and *blu* written in dark blue or in light blue, assumes that naming a dark blue color requires distinct RTs and degree of accuracy as compared to naming a light blue color if they are both combined to the Italian

color word *bleu*. This discrepancy would be absent in French stimuli: any differences would be registered for the color word *bleu* written in dark blue or in light blue. The four blue stimuli we analysed are: **Bleu** / **Bleu** / **Blu** / **Blu**: the stimuli **Bleu** and **Blu** were considered congruent stimuli, whereas the stimuli **Bleu** and **Blu** were analysed as incongruent stimuli. This choice is justified by the fact that dark blue is the focal color for the French color word *bleu*, as well as for the Italian word *blu* (Paggetti, Menegaz, and Paramei 2016; MacLaury, Paramei, and Dedrick 2007 Jraissati 2009).

We present the statistical results following the same design as for the Stroop Effect data: we start with monolingual speakers and we finish with the bilingual group, reporting both within-subjects comparisons and between-subjects comparison.

4.1.1.2.1 The Monolingual Speakers

4.1.1.1.2.1 The French Subjects

a. Behavioural Analysis

As for the Stroop Effect, we excluded from our data set of the French monolingual group all the incorrect responses (1.2%) as well as all the outliers (0% of correct trials).

ANOVA results for RTs and accuracy showed that French speakers (N= 22) were faster for incongruent stimuli (MEAN = 685.794 ms, SD = 110.747 ms) than for congruent stimuli (MEAN = 719.804 ms, SD = 151.049 ms). This unexpected effect, which means that they answered more rapidly to the color word *bleu* when it was written in light blue (**Bleu**) than when it was written in dark blue (**Blu**), will be discussed in the next section.

In contrast, error analyses brought opposite results: French monolingual speakers were more accurate for matching congruent stimuli (MEAN = 99.495%, SD = 2.369%) compared to incongruent (MEAN = 97.813%, SD = 8.128%).

b. Discussion

The French monolingual within-subjects statistical analysis attested the emergence of an unusual effect of congruency for blue stimuli reaction times, indicating that incongruent stimuli are named more rapidly than congruent stimuli. This phenomenon could be explained by prototypicality effects and/or by chromaticity effects. In fact, it could be possible that in French language the light blue color is perceived as more chromatic than dark blue hues, which leads to a higher degree of naming consensus. At the same time, the lexical and psychological treatment of words' meanings can rely on prototypical facets of the color hue, and this would be the case of light blue foci. If light blue hues are associated with the color word *bleu*, it would be necessary to suppose that changes in the French color lexicon have occurred, with a shift of the focal color towards hues with higher lightness values. However, further studies are needed to verify this hypothesis, which would call into question the coordinates of the focal color of the BCT *bleu* .

4.1.1.1.2.2 The Italian Subjects

a. Behavioural Analysis

In the Italian monolingual group, we eliminated 0.4% of incorrect responses and no outliers were present.

Statistical results demonstrated that Italian speakers (N=22) were faster for congruent stimuli (MEAN = 694.599 ms, SD = 115.050 ms) than for incongruent stimuli (MEAN = 718.978 ms, SD = 145.613 ms). This effect confirms the hypothesis that they answered more slowly when the color word *blu* was written in light blue (**Blu**) than when it was written in dark blue (**Blu**).

In error analyses we found an incongruent tendency since Italian monolinguals were more accurate for incongruent stimuli (MEAN = 97.917%, SD = 4.531%) compared to congruent stimuli (MEAN = 96.402%, SD = 6.395%).

b. Discussion

Italian statistical analysis demonstrated that naming the Italian word *blu* is a faster perceptual proceeding when it is written in dark blue (corresponding to the word *blu*) than naming the word *blu* when it is printed in light blue (corresponding to the word *azzurro*), as we expected.

However, this effect does not show up in error rates data which show that Italians are a little more accurate for incongruent stimuli: since the discrepancy in percentage is really low, we hypothesize that it is an effect of our experimental group characteristics. It would be necessary to replicate the experiment with another group of Italian monolingual speakers with similar characteristics, in order to corroborate this tendency.

4.1.1.1.2.3 French-Italian Between-Subjects Comparison

a. Behavioural Analysis

In the between-subject comparison between the two groups of monolingual native speakers, we performed two other two-way repeated measures analysis of variance (ANOVA C2 X G2) in which Congruency (C), made up of two levels (congruent and incongruent) was considered a within-subjects factor, and Group (G), made up of two levels (French and Italian) was the between-subjects factor.

Data analysis did not show any statistically significant effects or interactions neither for reaction times nor for error rates. The only result we consider interesting to report is the tendency ($p = 0.057$) between congruency and group ($F(1, 42) = 3.834$, $MSE = 4890.316$, $p = 0.057$, $\eta^2 = 0.013$), as graphically illustrated in figure 39. The inverted behaviour between Italian and French speakers as regards congruent and incongruent stimuli is particularly evident: as we discussed in the previous sections, Italians are faster for congruent stimuli than for incongruent stimuli, whereas French are more rapid in the color naming of incongruent stimuli compared to the congruent ones. As we explained in the previous paragraphs about French monolingual results, this behaviour was not expected.

In fact, if for Italian speakers we expected that congruent stimuli were discriminated faster than incongruent stimuli, for French monolingual speakers we predicted no relevant differences between congruent and incongruent stimuli in reaction times since light blue is associated to the color word *bleu*, like dark blue.

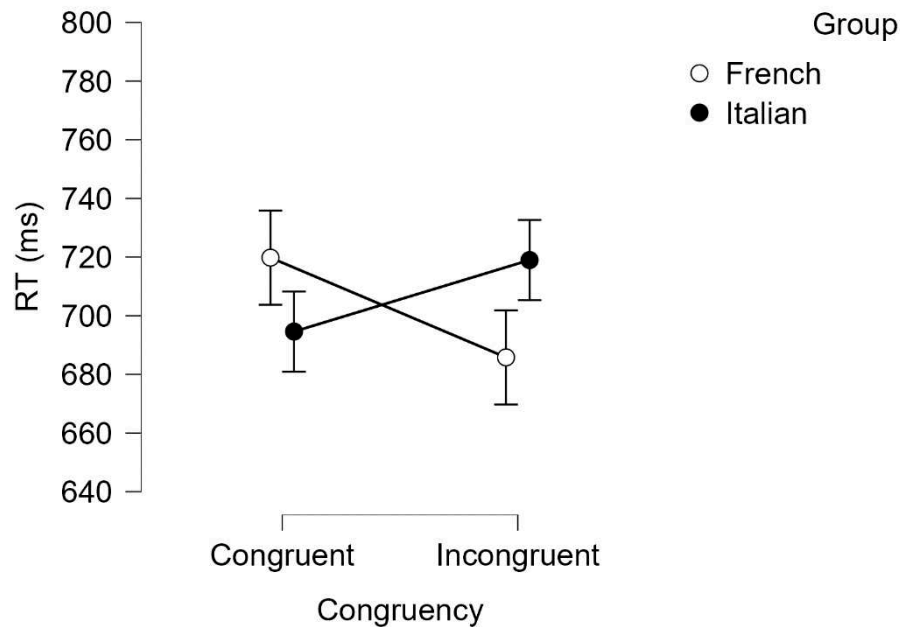


Figure 39: RTs in milliseconds for the Italian and French monolingual groups in the two stimuli conditions with Standard Error (SE) bars.

b. Discussion

For the Blue Color Word Effect, the two groups of monolingual speakers did not present statistically significant differences in accuracy and reaction times. The color words *bleu* and *blu* are, thus, similarly processed, even though the color (blue) of the French stimulus **Bleu** is named faster compared to the darker one **Blue**. This phenomenon is absent in Italian data, which validates our hypothesis of a perceptual congruency effect reflecting the lexical distinction effect of the two blue color words.

4.1.1.2.2 The French-Italian Bilingual Speakers

a. Behavioural Analysis

Before starting the bilingual within-subjects comparison, we eliminated from our data set all the incorrect responses (0.75%) and the outliers for each participant (0.10% of correct trials).

We conducted several repeated-measures ANOVA to explore the Blue Color Word Effect in the Stroop Experiment for the three experimental blocks of bilinguals. In our three-ways ANOVA (ANOVA L2 X C2 X M2) we put Language (French and Italian), corresponding to the language of stimuli, Congruency (Congruent vs Incongruent) and Mixing (No Mixed vs Mixed block), corresponding to the kind of experimental blocks, as repeated measures factors.

For reaction times, we obtained only a congruency effect ($F(1, 20) = 4.781$, $MSE = 25320.702$, $p = 0.041$, $\eta^2 = 0.041$), whose Post Hoc test has shown that bilinguals are globally 53.686 ms faster for blue congruent stimuli than for blue incongruent stimuli ($p^{\text{holm}} = 0.041$), regardless of the experimental block type (Figure 41).

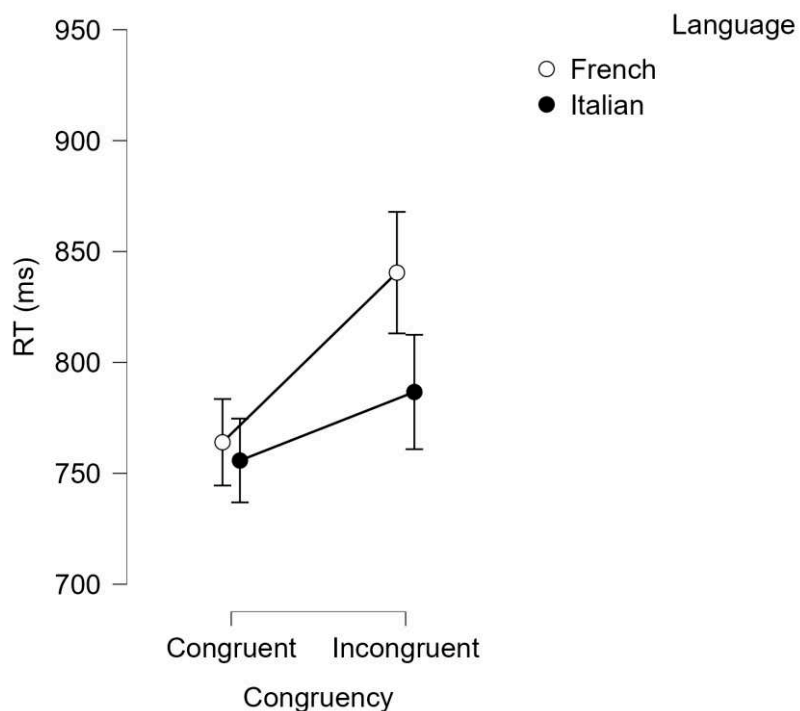


Figure 40: Global Reaction Times in milliseconds for French and Italian congruent and incongruent stimuli with Standard Error (SE) bars.

Moreover, through descriptive statistics we can have a global portrait of latencies for French and Italian stimuli, both in congruent and in incongruent conditions, in the monolingual block (only Italian or only French color words), as well as in the mixed block (*bleu* and *blu* color words in the same experiment).

In Table 5, Mean and Standard Deviation attest in detail that all the stimuli in the mixed block are named faster than stimuli in the two other monolingual blocks, both when the color and the semantics of the color word match and when the color ink-semantics correspondence does not match. This is probably a training effect due to familiarity with the task.

French incongruent stimuli, in mixed and no mixed experimental blocks, are named 76.479 ms later compared to French congruent stimuli (SD= 64.6825 ms), whereas Italian incongruent stimuli, in mixed and no mixed experimental blocks, are slower, too (MEAN = -30.8925 ms, SD = 50.78 ms).

Descriptives

Language	Congruency	Mixing	Mean	SD	N
French	Congruent	No Mixte	784.467	149.351	21
		Mixte	743.542	135.428	21
	Incongruent	No Mixte	853.919	199.107	21
		Mixte	827.048	215.037	21
Italian	Congruent	No Mixte	765.811	111.167	21
		Mixte	745.736	125.271	21
	Incongruent	No Mixte	810.856	150.771	21
		Mixte	762.476	187.227	21

Table 5: Mean Reaction Times and Standard Deviation (in ms) for French and Italian congruent and incongruent stimuli, in mixed and no mixed experimental blocks, performed by bilinguals.

ANOVA measures of errors did not display any effects nor interactions: the bilingual group had a similar rate of accuracy in processing congruent and incongruent stimuli in French and Italian in the monolingualistic and in the mixed blocks: they are just a little more accurate in Italian color naming compared to French, as we can see in Figure 41.

In the Annexes, we attached more detailed charts about accuracy in French and Italian stimuli, differentiating between the two non-mixed blocks and the mixed block.

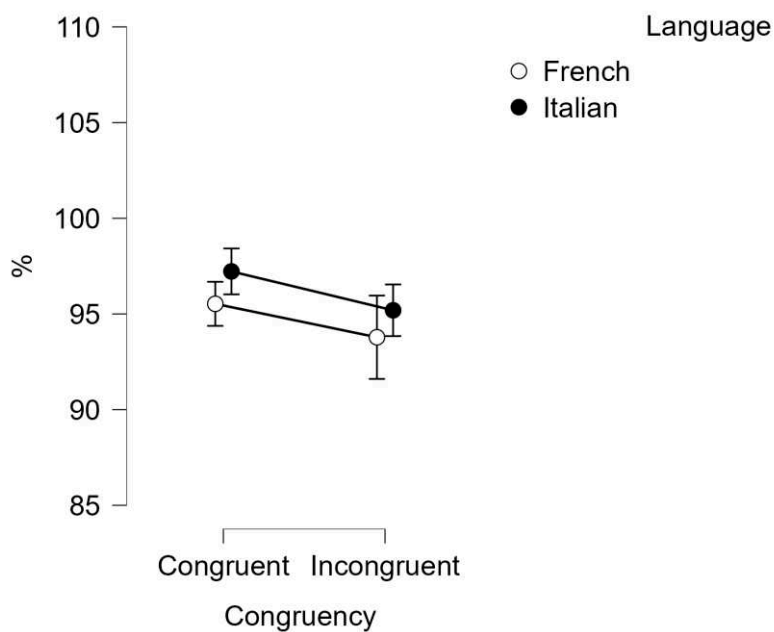


Figure 41: Accuracy in percentage (%) for French and Italian congruent and incongruent stimuli performed by the bilingual group, regardless of the kind of experimental block, with Standard Error (SE) bars.

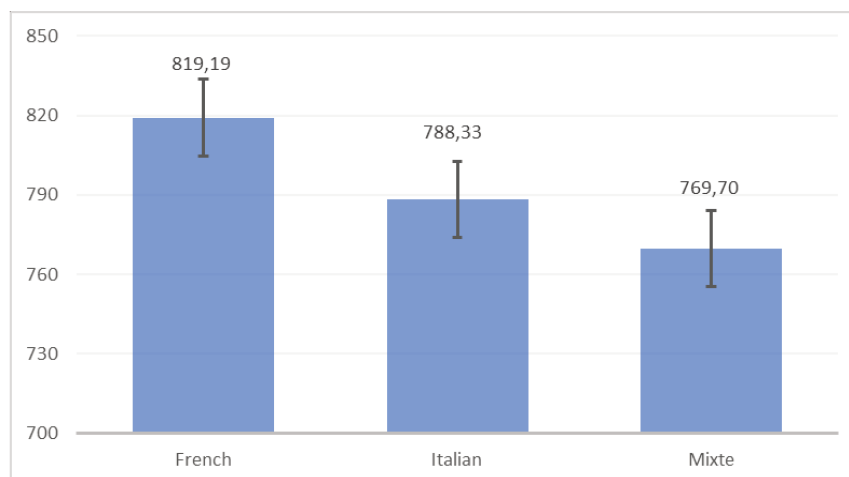
b. Discussion

Bilingual speakers' analyses demonstrated that bilinguals equally performed a color naming task with French and Italian color words defining the blue spectrum. The expected effect of congruency was detected, as like in the other groups' comparison. However, the lack of statistically significant differences between French and Italian stimuli in reaction

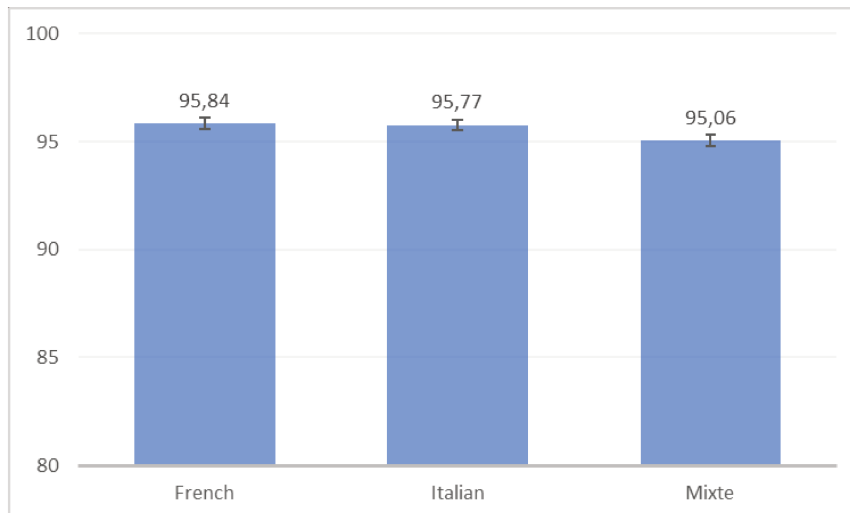
times and error rates means that bilingual speakers manage and adopt one conceptual system: the Italian one.

In fact, bilinguals applied the lexical color discrimination between the two blue hues to the French color word *blue* which covers the entire blue color area. As a result, their second language categorization dominates their first language categorization, influencing color perception. The small difference in RTs between Italian and French stimuli, for which the Italian color naming is faster, is not statistically salient but can be associated with inhibition costs in adopting the other language's conceptual system.

Furthermore, as we mentioned above, the mixed block reported better performances and faster reaction times: this result is due to the training effect and the familiarity with the task, even though each participant had to memorize new different correspondences between response keys and color ink at the beginning of each experimental block (Graph 3 and 4).



Graph 3: Global mean reaction time (in milliseconds) for the Blue Color Word Effect in the three experimental blocks (with French stimuli, with Italian stimuli and with mixed French and Italian stimuli) performed by bilinguals with Standard Error (SE) bars.



Graph 4: Global mean Accuracy (in percentage) for the Blue Color Word Effect in the three experimental blocks (with French stimuli, with Italian stimuli and with mixed French and Italian stimuli) performed by bilinguals with Standard Error (SE) bars.

4.1.1.2.2.1 French vs Bilingual Subjects Comparison

a. Behavioural Analysis

For the Blue Color Word Effect in the Stroop Experiment, we compared the group of French monolinguals with the L1 of the French-Italian bilinguals in order to explore whether the conceptual and lexical system of the second language (Italian) has an impact on tasks with French perceptual stimuli.

We, thus, performed repeated-measures ANOVA (C2 X G2) for the analysis of reaction times and accuracy, with Congruency (C) and Group (G) as respectively within-subjects factor and between-subject factor. Analyses of RTs have shown an interaction between Congruency and Group ($F(1, 41) = 6.659$, $MSE = 8636.134$, $p = 0.014$, $\eta^2 = 0.025$) and a significant effect of Group ($F(1, 41) = 7.360$, $MSE = 39551.346$, $p = 0.010$, $\eta^2 = 0.125$).

We performed a Post Hoc test to explore RTs distributions of the interaction between Congruency and Group: data informed us that French speakers were faster in naming congruent stimuli compared to incongruent stimuli of bilinguals performing the French experiment ($p^{\text{holm}} = 0.032$, $MD = -134.114$ ms), as well as that bilinguals were 168.125 ms

slower in naming incongruent stimuli (**Bleu**) compared to the French group, always in incongruent stimuli color naming ($p^{\text{holm}} = 0.005$), as we can see in Figure 42.

On the other hand, Post Hoc analysis for group effect demonstrated that bilinguals performing the French experimental block are globally slower than the corresponding French monolingual group ($p^{\text{holm}} = 0.010$, MD= 116.393 ms).

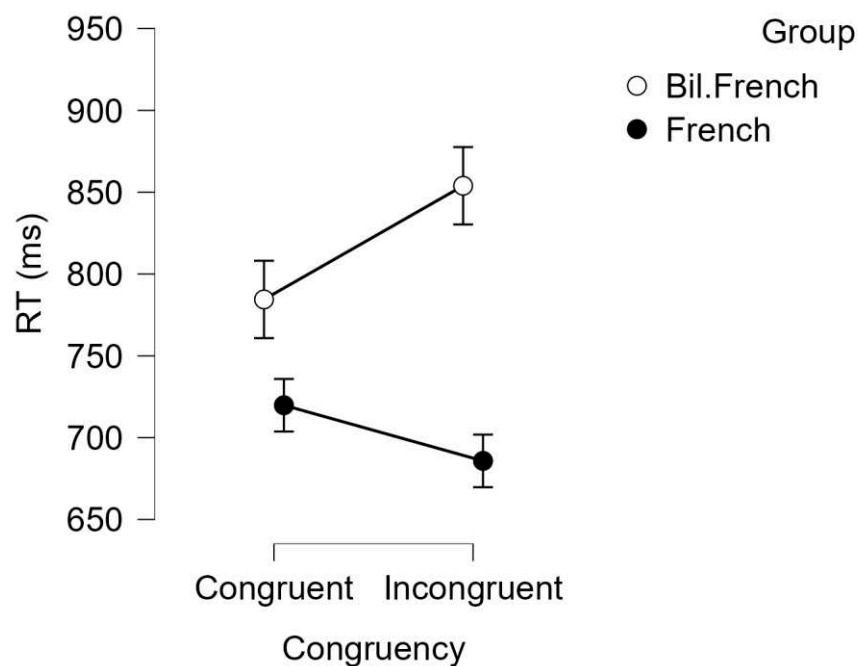


Figure 42: Reaction Times in milliseconds for French monolingual speakers and bilingual speakers in the French experiment in the two stimuli conditions, with Standard Error (SE) bars.

The ANOVA performed for error rates have revealed a marginally significant group effect ($F(1, 41) = 3.972$, $MSE = 42.796$, $p = 0.053$, $\eta^2 = 0.041$), whose Post Hoc test showed that, for the French word *bleu*, bilinguals are globally 2.812% less accurate performing the French Stroop experiment than French monolinguals ($p^{\text{holm}} = 0.053$), as clarified in Figure 43.

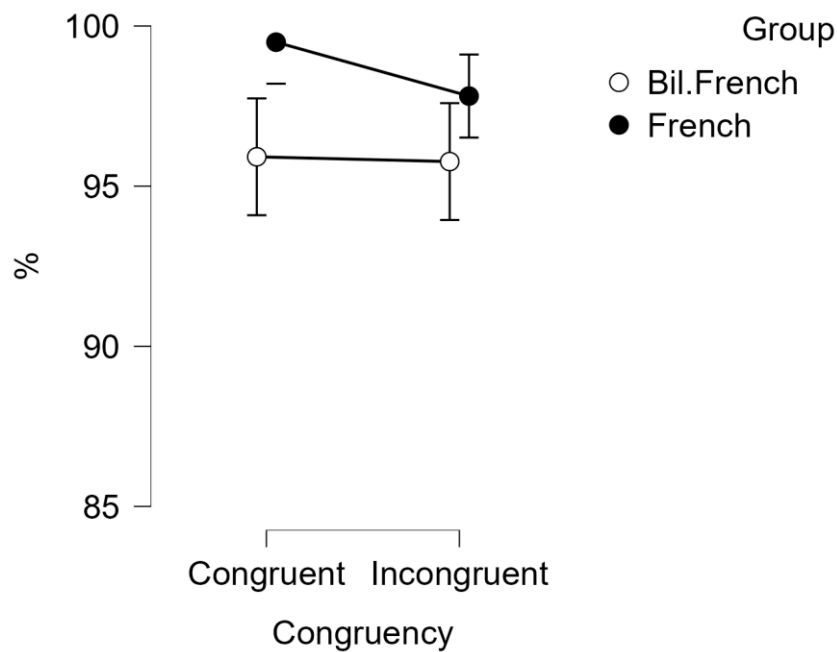


Figure 43: Accuracy in percentage (%) for French monolinguals and the bilingual group in the L1 French experiment in the two blue stimuli conditions, with Standard Error (SE) bars.

b. Discussion

Performances for French blue stimuli of the Color Word Stroop Task have been analysed in a contrastive approach in French monolingual speakers and French-Italian proficient bilingual speakers performing the French Stroop experiment.

Statistical results have validated our hypothesis suggesting that bilinguals probably adopt the Italian lexical system, distinguishing the two blue hues through two BCTs, even for French linguistic stimuli. The perceptual task requiring the attention on the chromatic feature of the stimuli, indirectly attests the impact of linguistic labelling on the perceptive mechanisms.

However, cognitive costs, due to the inhibition of one of the two conceptual categorizations, as well as conflicts linked to different BCCs which can even create hesitation in decision making, can explain the global major slowness and inaccuracy of bilingual speakers as compared to the corresponding monolinguals.

4.1.1.2.2.2 Italian vs Bilingual Subjects Comparison

a. Behavioural Analysis

The last between-groups comparative analysis we conducted measured statistical differences between Italian monolingual speakers and bilingual speakers tested in the Italian Stroop experiment, or in their second language (L2).

Two-ways repeated-measures ANOVA (C2 X G2) have been performed for error analysis and reaction times; an effect of congruency and a group effect has been detected for RTs (Figure 44), whereas accuracy statistics showed a Congruency X Group interaction (Figure 45).

The Post Hoc test performed to explore distributions of the congruency effect ($F(1, 41) = 4.398$, $MSE = 25892.236$, $p = 0.042$, $\eta^2 = 0.016$) revealed that the two groups were globally 34.712 ms more rapid for congruent stimuli compared to incongruent stimuli ($p^{\text{holm}} = 0.042$), corresponding to a traditional Stroop Effect with the two blue BCTs trials.

Nevertheless, the Post Hoc test for RTs distributions of the group effect ($F(1, 41) = 4.950$, $MSE = 28869.172$, $p = 0.032$, $\eta^2 = 0.090$) attested that the bilingual group performing the Italian Stroop Experiment was slower than the Italian monolingual group ($p^{\text{holm}} = 0.032$, $MD = 81.545$ ms), both in congruent and incongruent blue stimuli. However, the two groups similarly behave in the mean difference time gap for naming the color word *blu* written in dark blue and for naming the color word *blu* written in light blue, or *azzurro*.

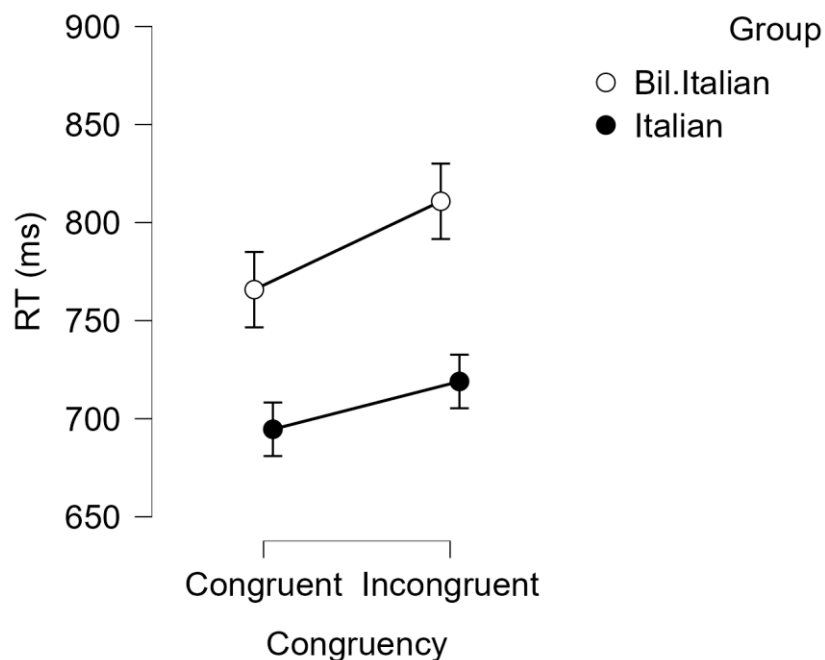


Figure 44: Reaction Times in milliseconds for the Italian monolingual group and bilingual speakers in the Italian experiment in the two blue color words stimuli conditions, with Standard Error (SE) bars.

Figure 45 details the accuracy statistical results which reported a strong interaction between congruency and group ($F(1, 41) = 6.270$, $MSE = 39.680$, $p = 0.016$, $\eta^2 = 0.070$). However, the Post Hoc test did not show significant distributional outcomes: we can only mention a marginally significant effect ($p^{\text{holm}} = 0.057$, $MD = 5.290\%$) between congruent stimuli accuracy compared to incongruent stimuli in bilinguals (within-subjects discrepancy), and a tendency ($p^{\text{holm}} = 0.070$, $MD = -4.794\%$) involving error rate of bilinguals for incongruent stimuli vs. error rate of Italian monolinguals for incongruent stimuli. The bilingual group is, thus, greatly less accurate in naming the color ink of **Blu** than their corresponding monolingual group.

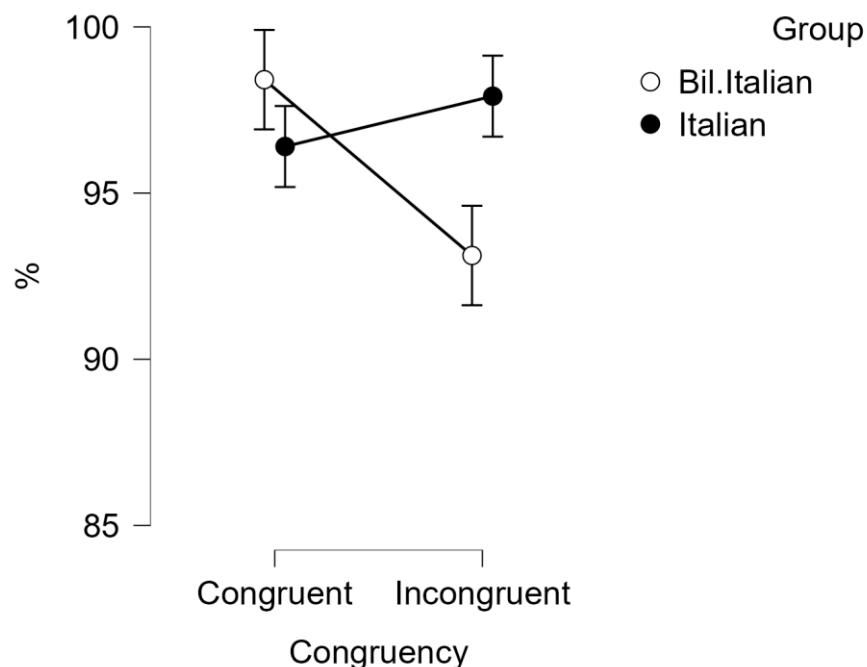


Figure 45: Accuracy in percentage (%) for Italian monolinguals and the bilingual group in the L2 Italian experiment in the two blue stimuli conditions, with Standard Error (SE) bars.

b. Discussion

The statistical analysis of the data set collected for Italian speakers and bilinguals in the Italian experimental block attested that the latter behave like monolingual native speakers, especially in reaction times latencies. This would be explained by the fact that their linguistic proficiency in the L2 has allowed them to adopt and interiorize the L2 categorization for the Italian perceptual task, which has become their dominant conceptual system, as we hypothesized.

However, the major error rate for bilingual incongruent stimuli does not correspond to the accuracy for Italian monolinguals' performances for incongruent stimuli: this marginal phenomenon can be explained as an effect due to the characteristics of our experimental group.

As for the previous comparative analyses, the overall greater latencies and inaccuracy are probably caused by bilingual cognitive costs which impact performances.

4.1.2 The Speeded Color Discrimination Task

In the second part of this chapter, we will present the results obtained by the Speeded Color Discrimination Task for each group of speakers. We will keep the same organization as for Color Word Stroop Task results: firstly, we will analyse and discuss the results of the two monolingual groups and then those of the bilingual group; the last comparison will add the group factor as a between-subjects factor in order to detect possible effects or interactions depending on group.

We performed several repeated-measures ANOVA for accuracy and reaction times recordings to analyse the Color Patch Effect, or the impact of color category, distinguishing between light blue and dark blue patches, on perceptual performance, as well as the Category Advantage, or the faster and more accurate discrimination of color stimuli belonging to different BCCs compared to those of the same color category in the blue spectrum. Analyses of the two interference stimuli have been conducted, too.

From a methodological point of view, we removed for each participant all the outliers and the responses of more than 3000 ms, following the protocol of Winawer's study.

4.1.2.1 The Color Patch Effect Results

We defined the Color Patch Effect as the statistically significant effects or interactions obtained by the comparison between dark blue patches and light blue patches, based on the individual chromatic boundary determined by each participant.

The main purpose is, in fact, to examine whether there exists a correlation between the two color patch categories, where all the stimuli falling in the dark blue category are put together as well as all the light blue stimuli, and the perceptual chromatic distance in the three experimental blocks. For each participants' group (within-subjects comparison), we performed several three-ways repeated-measures ANOVA (I3 X C2 X D2) where Interference, made up of three levels (No Interference block, Verbal Interference block,

Spatial Interference block), Color Patch (dark blue - *blu / bleu* - or light blue - *azzurro / bleu*) and Distance (Near, Far) are considered as Repeated Measures Factors.

Reaction times and error rates were recorded and analysed.

4.1.2.1.1 The Monolingual Speakers

4.1.2.1.1.1 The French Subjects

a. Behavioural analysis

For the French monolingual group (N=22), we excluded from the data set outliers for each participant (0,6% of correct trials) and incorrect responses (4,3%).

Results for reaction times showed two main statistically relevant effects: a Color Patch effect ($F(1, 21) = 55.013$, $MSE = 14290.244$, $p < .001$, $\eta^2 = 0.193$) and an effect of Distance ($F(1, 21) = 79.121$, $MSE = 13343.252$, $p < .001$, $\eta^2 = 0.259$).

We explored the distribution of Color Patch Effect ($p^{\text{holm}} < .001$) for RTs through a Post Hoc test which revealed that dark blue patches (MEAN= 762.136 ms, SD= 143.890 ms) are discriminated 109.139 ms faster than light blue patches (MEAN= 859.272 ms, SD= 179.263 ms). On the other hand, the Post Hoc analysis for Distance revealed that responses for far stimuli (MEAN= 743.741 ms, SD= 140.503 ms) are 126.475 ms faster than near stimuli (MEAN= 870.216 ms, SD= 180.676 ms), without any distinction between dark and light blue hues.

In Figure 46 we illustrated the RTs' Color Patch Effect, where BLU and AZZURRO represent the two color categories in the three experimental blocks, and RTs' Distance Effect in Figure 47.

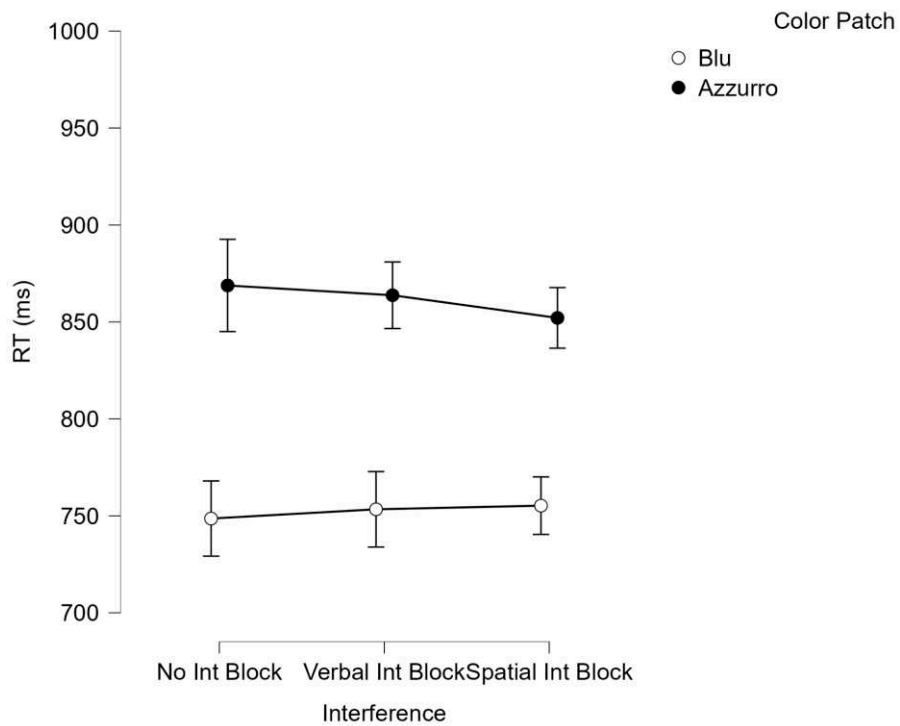


Figure 46: RTs in milliseconds for dark blue and light blue color patches, in the three interference blocks, for French monolinguals, with Standard Error (SE) bars.

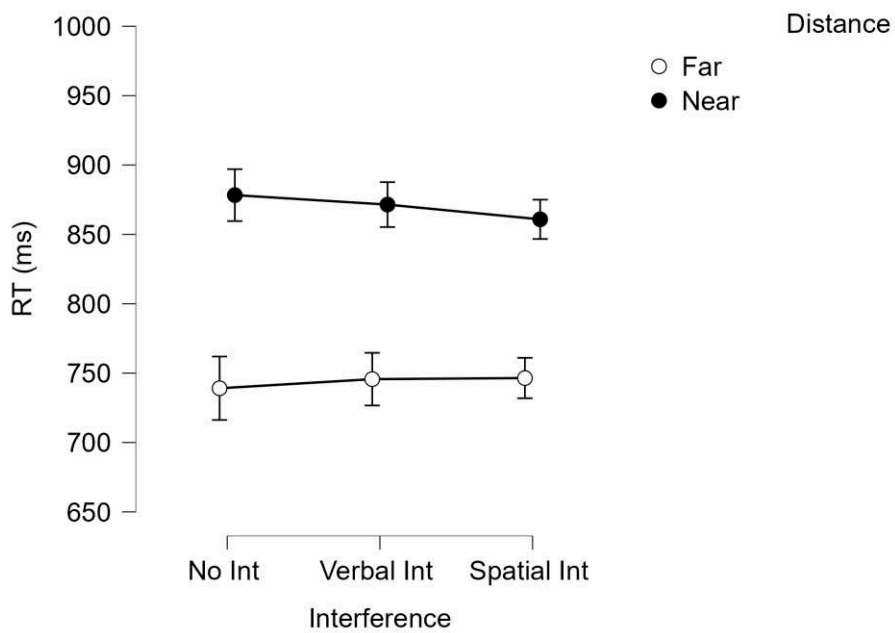


Figure 47: RTs in milliseconds for far and near color patches, in the three interference blocks, for French monolinguals, with Standard Error (SE) bars.

We have found a Color Patch effect also for accuracy ($F(1, 21) = 11.260$, $MSE = 88.914$, $p = 0.003$, $\eta^2 = 0.143$) whose Post Hoc test displayed global more accurate responses ($p^{\text{holm}} = 0.003$) of about 5.508% for dark blue patches ($MEAN = 84.126\%$, $SD = 9.423\%$) compared to light blue patches ($MEAN = 78.618\%$, $SD = 12.287\%$). Figure 48 graphically details this effect.

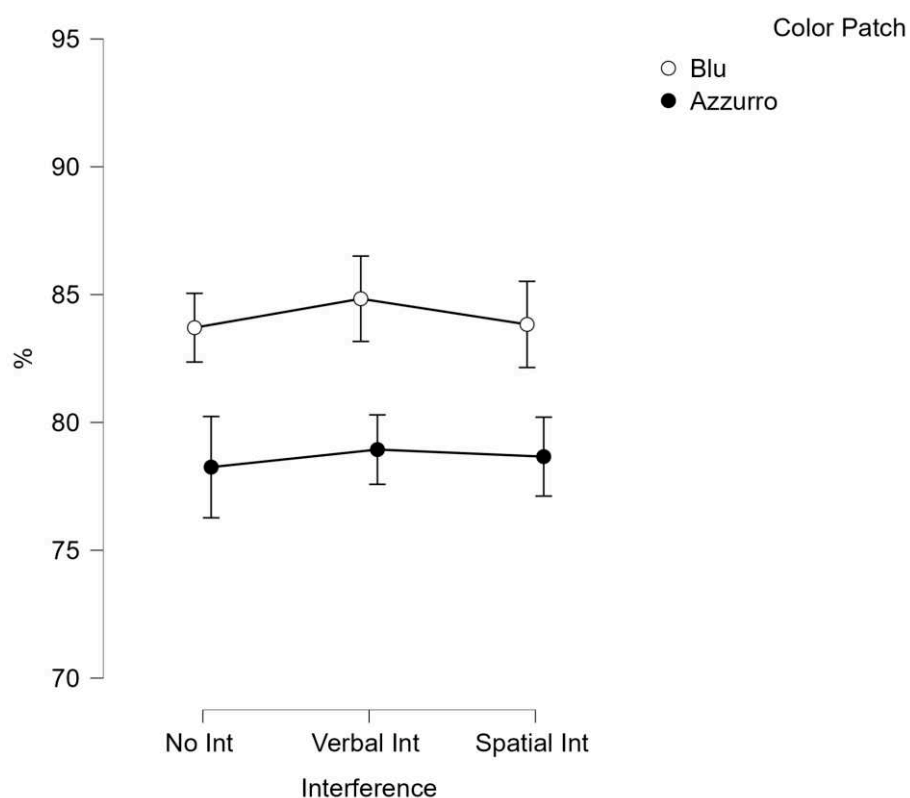


Figure 48: Accuracy in percentage for dark blue and light blue color patches, in the three interference blocks, for French monolinguals, with Standard Error (SE) bars.

b. Discussion

The within-subjects comparison for French monolingual speakers has shown that dark blue patches are better and faster discriminated than light blue patches: this effect is probably due to the blue focal color which corresponds to a dark hue of the blue spectrum in French. Therefore, French speakers' naming consensus is higher for all the stimuli falling

into the BLU category, which, in turn, impacts color perception. However, this effect seems to conflict with the Stroop results which have demonstrated a possible shift of the blue focal color in French towards lighter hues. This supposition needs to be explored through additional experiments in order to redefine the color coordinates of the blue focal color.

Moreover, as we expected, in French there exists a facilitatory effect for far stimuli, easier to detect, compared to near stimuli, for which perceptual differences are finer: these results, thus, validate our hypothesis. In contrast, the expected facilitatory effect for near stimuli in Italian speakers has not been detected, as we will show in the following section.

4.1.2.1.1.2 The Italian Subjects

a. Behavioural analysis

For the Italian monolingual group (N=22), the rate of incorrect responses excluded was 5% and individual participants' outliers were 0,8% of correct trials.

The three-ways ANOVA analyses we conducted for reaction times demonstrated an effect of Color Patch ($F(1, 21) = 4.628$, $MSE = 5674.206$, $p = 0.043$, $\eta^2 = 0.007$), an effect of Distance ($F(1, 21) = 127.539$, $MSE = 14603.876$, $p < .001$, $\eta^2 = 0.514$), as well as a significant triple interaction between Interference, Color Patch and Distance ($F(2, 42) = 3.886$, $MSE = 2214.670$, $p = 0.028$, $\eta^2 = 0.005$). We, then, performed several Post Hoc tests to explore distributions: for the Color Patch Effect ($p^{\text{holm}} = 0.043$) we discovered that, contrary to French participants, dark blue stimuli (MEAN= 842.146 ms, SD= 119.921 ms), labeled with the color word *blu*, were discriminated 19.946 ms slower than light blue stimuli (MEAN= 816.604 ms, SD= 115.243 ms), correlated to the color word *azzurro*. However, for the Distance Effect ($p^{\text{holm}} < .001$) we obtained similar results as the French group: far stimuli (MEAN= 744.057 ms, SD= 94.698 ms) were discriminated 167.990 ms faster than near stimuli (MEAN= 912.047 ms, SD= 143.605 ms).

In Figure 49 we reported RTs results for the Color Patch Effect for Italian monolinguals with interference conditions on the horizontal axis and color patch (*blu* vs *azzurro*) on the vertical axis. In Figure 50, however, we reported RTs results for the Distance Effect with interference conditions on the horizontal axis and far-near distinctions on the vertical axis. In this latter case, we can observe the lack of facilitatory effect for near stimuli, which we expected: near color patches are highly slowly discriminated compared to far color patches.

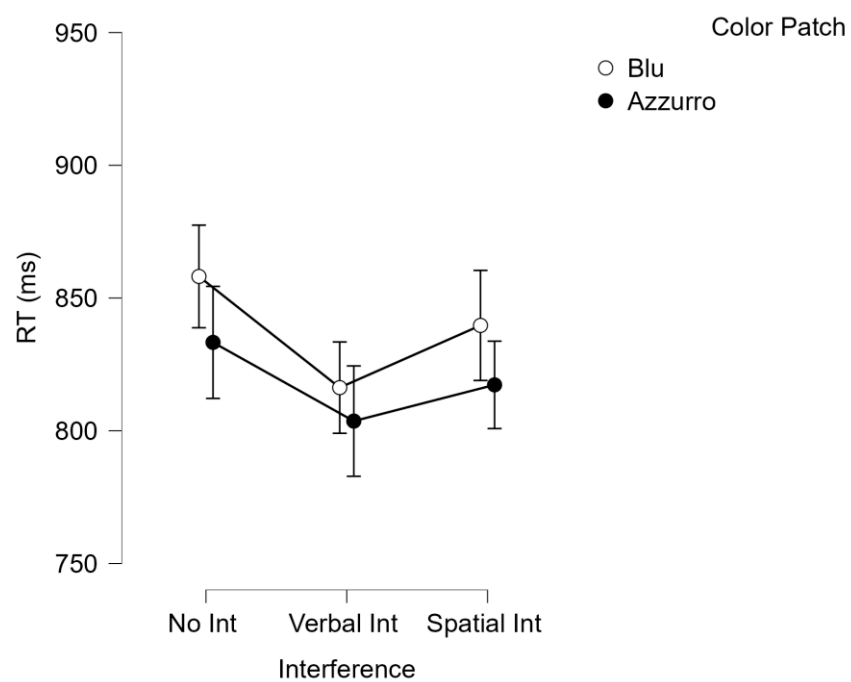


Figure 49: Reaction Times (in milliseconds) for dark blue and light blue patches, in the three interference blocks, for Italian monolinguals, with Standard Error (SE) bars.

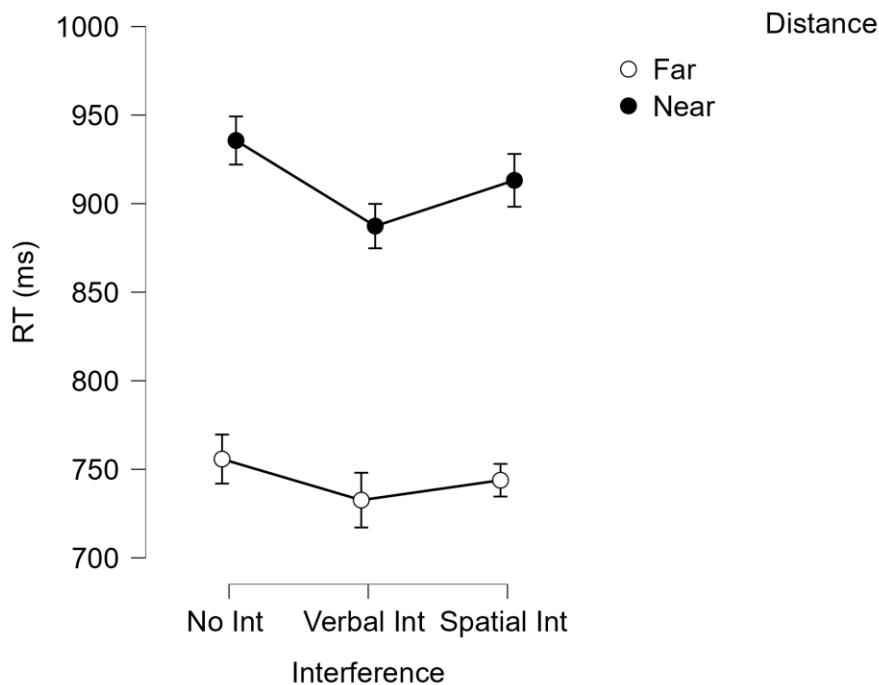


Figure 50: Reaction Times (in milliseconds) for far and near stimuli, in the three interference blocks, for Italian monolinguals, with Standard Error (SE) bars.

Lastly, to analyse the RTs distributions of the Interference X Color Patch X Distance interaction, we performed a Post Hoc test, and we studied different Simple Main Effects. Results showed that the Color Patch factor had an impact especially on the discrimination of far trials in the No Interference block ($F(1) = 7.887$, $MSE = 13050.801$, $p = 0.011$), as well as in near trials in the Spatial Interference block ($F(1) = 5.210$, $MSE = 20948.982$, $p = 0.033$). In fact, latencies for dark blue far stimuli (Italian BLU category) in No Interference block (MEAN = 772.994 ms, SD = 150.100 ms) were 34.445 ms slower than light blue far stimuli (Italian AZZURRO category) in No Interference block (MEAN = 738.549 ms, SD = 136.216 ms).

Moreover, latencies for dark blue near stimuli (Italian BLU category) in the Spatial Interference block (MEAN = 934.981 ms, SD = 179.291 ms) were 43.640 ms slower than light blue near stimuli (Italian AZZURRO category) in the Spatial Interference block (MEAN = 891.342 ms, SD = 145.375 ms).

The ANOVA analysis for accuracy reported an effect for Color Patches Effect ($F(1, 21) = 12.841$, $MSE = 27.631$, $p = 0.002$, $\eta^2 = 0.153$): descriptive statistics and Post Hoc tests (p^{holm}

= 0.002) attested that Italian speakers were 3.279% more accurate for patches belonging to the AZZURRO color category (MEAN= 94.209%, SD= 2.613%) compared to patches belonging to the BLU color category (MEAN= 90.930%, SD= 4.039%).

Figure 51 exemplifies the error rates of *blu* and *azzurro* patches in the three experimental blocks.

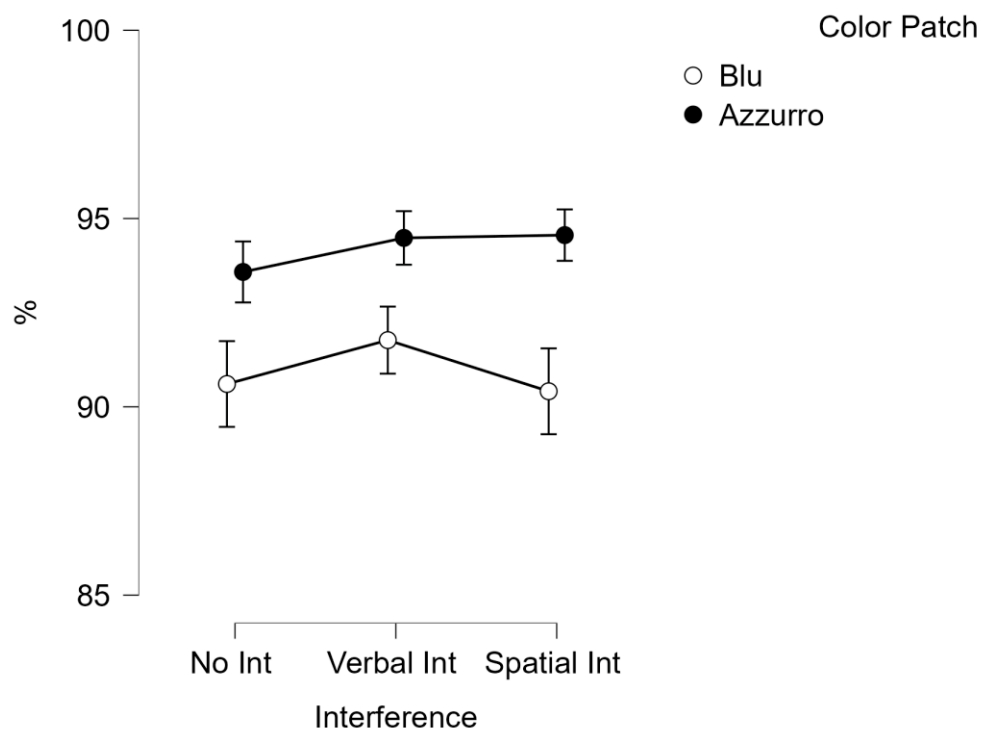


Figure 51: Accuracy (in percentage) for dark blue and light blue color patches, in the three interference blocks, for Italian monolingual speakers, with Standard Error (SE) bars.

b. Discussion

The within-subjects comparison for Italian monolingual speakers has revealed a trend partially different from that of French monolinguals. In fact, light blue patches are faster discriminated than dark blue patches: this effect can support the theory that in Italian there exists the AZZURRO color category, which is considered as basic, like the BLU one. Moreover, the type of color patch has an influence especially on trials of the No

Interference Block and in trials of the Spatial Interference Block, the two blocks which are supposed to be mostly impacted by language processing, through distinct lexical color categories.

4.1.2.1.2 The French-Italian Bilingual Speakers

a. Behavioural analysis

For the French-Italian bilingual group (N=21), 6% of incorrect responses were excluded, as well as 0% of individual outliers per participant.

The three-ways ANOVA analyses performed for reaction times showed an effect of Color Patch ($F(1, 17) = 42.678$, $MSE = 12504.124$, $p < .001$, $\eta^2 = 0.148$) and an effect of Distance ($F(1, 17) = 142.760$, $MSE = 8707.322$, $p < .001$, $\eta^2 = 0.346$). However, a marginal interaction between Interference and Distance has been detected ($F(2, 34) = 2.954$, $MSE = 4329.848$, $p = 0.066$, $\eta^2 = 0.007$): far stimuli are globally more rapid than near stimuli in all the experimental blocks, without any distinctions between *blu* and *azzurro* patches.

Post Hoc tests have been conducted for analysis distributions of the two effects: the Color Patch Effect ($p^{\text{holm}} < .001$) displayed that *blu* stimuli (MEAN= 830.432 ms, SD= 166.940ms) were discriminated 99.410 ms faster than *azzurro* stimuli (MEAN= 923.237 ms, SD= 191.164 ms). On the other hand, for the Distance Effect ($p^{\text{holm}} < .001$) we obtained similar results as the two other groups: far stimuli (MEAN= 804.003 ms, SD= 161.939 ms) were discriminated 151.722 ms faster than near stimuli (MEAN= 949.062 ms, SD= 195.065 ms). These two effects are illustrated respectively in Figure 52 and Figure 53.

Statistical results for error rates did not show any significant effect: the two color hues are processed with the same degree of accuracy (BLU patches: MEAN= 79.906%, SD= 17.292%; AZZURRO patches: MEAN= 77.908%, SD= 14.630%).

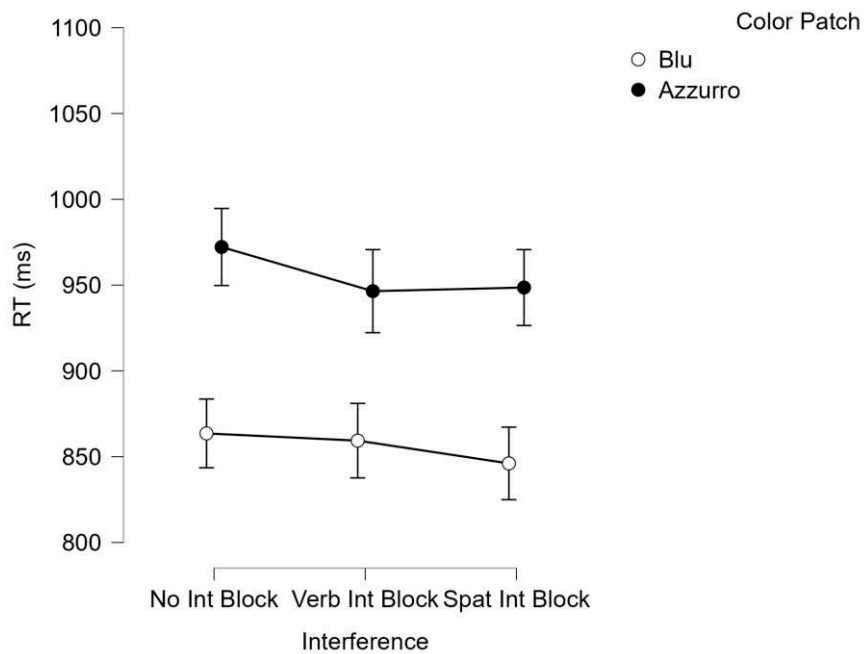


Figure 52: Reaction Times (in milliseconds) for BLU and AZZURRO stimuli in the three interference blocks, for bilinguals, with Standard Error (SE) bars.

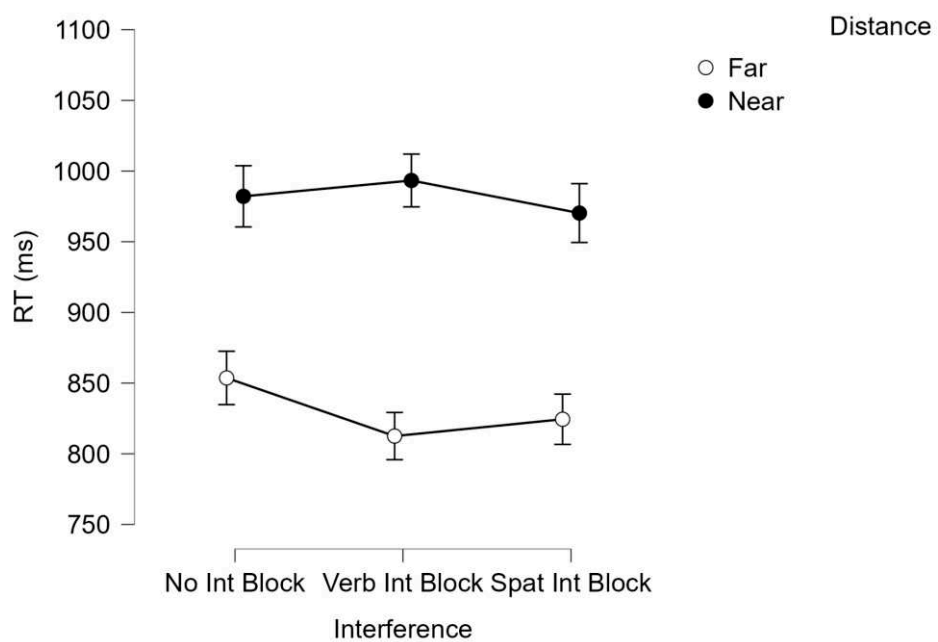


Figure 53: Reaction Times (in ms) for far and near stimuli in the three interference blocks, for bilinguals, with Standard Error (SE) bars.

b. Discussion

The major bilingual statistical result we obtained concerns the dark blue color patches which are discriminated more rapidly than light blue patches. This effect is probably due to the BLU focal color of bilinguals which is simultaneously that of their first language (French) and that of their second language (Italian). However, there is no distinction between the interference blocks, which means that the color of the patches is probably processed without any online direct influence of language on perception.

4.1.2.1.3 Between-Groups Comparison

a. Behavioural analysis

After the three within-subjects comparisons, we made an ANOVA between-subjects comparison adding the factor Group as a between-subjects factor with the aim to detect potential correlation between the Color Patch Effect and the three participants' groups in interaction.

Reaction times analyses showed several significant effects, whereas accuracy analyses were not statistically salient.

As in the three previous studies, we obtained a Color Patch effect ($F(1, 61) = 72.267$, $MSE = 751321.273$, $p < .001$, $\eta^2 = 0.029$) and a Distance effect ($F(1, 61) = 343.536$, $MSE = 41930000$, $p < .001$, $\eta^2 = 0.161$), but we also detected an effect of Group ($F(2, 61) = 3.389$, $MSE = 211959.861$, $p = 0.040$, $\eta^2 = 0.055$) and two interactions: a double Color Patch X Group Interaction ($F(2, 61) = 32.244$, $MSE = 10396.533$, $p < .001$, $\eta^2 = 0.026$) and a triple Interference X Distance X Group Interaction ($F(4, 122) = 3.952$, $MSE = 4036.917$, $p = 0.005$, $\eta^2 = 0.002$).

We, thus, performed several Post Hoc tests.

The Color Patch Effect distributions ($p^{\text{holm}} < .001$) displayed that patches of the BLU category (MEAN = 821.007 ms, SD = 129.814 ms) were discriminated faster than AZZURRO

category stimuli (MEAN= 876.170 ms, SD= 151.020 ms): MD= -62.618 ms; whereas the Distance Effect distributions ($p^{\text{holm}} < .001$) showed that latencies for far stimuli (MEAN= 772.133 ms, SD= 123.151 ms) were 147.927 ms faster than latencies for near stimuli (MEAN= 920.016 ms, SD= 157.988 ms).

The Post Hoc for the Group Effect revealed that the effect is significant ($p = 0.047$) for the group of bilinguals vs the French monolinguals: the former was, in fact, globally 101.925 ms slower compared to the latter.

Deeper analyses of the two interactions detected have exhibited the following results: for the Group X Color Patch Interaction, we discovered that bilinguals were faster ($p^{\text{holm}} < .001$, MD= -98.662 ms) in the BLU stimuli compared to AZZURRO stimuli, and that French were also faster ($p^{\text{holm}} < .001$) in the discrimination of BLU patches compared to AZZURRO patches (MD= -109.139 ms), as well as compared to bilinguals in AZZURRO patches discriminations (MD= -205.825 ms). Moreover, bilinguals' latencies were 140.155 ms slower ($p^{\text{holm}} = 0.017$) for AZZURRO patches compared to Italians' discrimination of AZZURRO patches.

Furthermore, the RTs distributional analyses of the triple Interference X Distance X Group Interaction have attested that the group has a main effect on certain experimental conditions, notably in far stimuli discriminations in the No Interference block ($p = 0.034$), in the near stimuli discriminations ($p = 0.024$) and in the far stimuli ($p = 0.050$) in the Verbal Interference block. At the same time, the Distance is the only factor exercising a significant effect on the two other factors: far and near stimuli are, in fact, always statistically differently discriminated in the three participants' groups in the three experimental interference conditions ($p < .001$).

a. Discussion

The between-subjects comparison analysis has allowed us to explore whether the results obtained for each experimental group have a statistically significant correlation. The more salient effect is a global slowness of bilinguals compared to the two groups of monolinguals in almost all the conditions. In fact, it seems that they adopt the color

categorization of their second language (Italian) but their performances are not exactly the same as the Italians ones. Therefore, the maximal discrepancy is between bilinguals and French monolinguals, which means that the former behaviourally deviate from their first language conceptual system.

However, a universal trend between the three groups is maintained in perceptually distant and close patches, independently of the BLU or AZZURRO category, in some experimental blocks.

4.1.2.2 The Category Advantage Results

The main effect we analysed in the Speeded Color Discrimination Task is the emergence of the Category Advantage (Winawer et al. 2007), or the faster and more accurate discrimination of patches belonging to the same color category compared to patches of different color categories. In the first case, when the match and the distractor squares belong to the same color category, we have within-category trials, whereas cross-category trials were trials where the match and the distractor belonged to different color categories (the two Italian BLU and AZZURRO).

The Category Advantage (CA) is calculated as the difference between the mean reaction time of within-category trials and the mean reaction time of cross-category trials. The effect of distance (near-far) is an additional factor which presupposes that CA is more pronounced for near colours discrimination than for far colours discrimination since the former were perceptually similar, thus, harder to distinguish.

We explored this effect, in RTs and accuracy, by performing several separate three-ways repeated-measures ANOVAs ($2 \times 3 \times 2$) calculated for each language group, where Interference was made up of three levels (No Interference, Verbal Interference and Spatial Interference), Category was made up of two levels (within-category and cross-category) and Distance was made up of two levels (far and near colours), too.

For each group of participants, incorrect responses and individual outliers were excluded for each participant: the rate was the same as for the analysis of the Color Patch Effect.

4.1.2.2.1 The Monolingual Speakers

4.1.2.2.1.1 The French Subjects

c. Behavioural analysis

ANOVA results for monolingual French speakers (N= 22) attested the emergence of a Category effect and a Distance effect both for reaction times and for accuracy.

Descriptive statistics and a Post Hoc test have shown that, for the RTs Category effect ($F(1, 21) = 10.703$, $MSE = 6457.062$, $p = 0.004$, $\eta^2 = 0.028$), within-category trials (MEAN= 828.973 ms, SD= 163.266 ms) are slower discriminated than cross-category trials (MEAN= 792.344 ms, SD= 168.451 ms): $p^{\text{holm}} = 0.004$, MD= 32.360 ms. However, descriptive statistics and a Post Hoc test for the effect of distance ($F(1, 21) = 66.505$, $MSE = 11845.906$, $p < .001$, $\eta^2 = 0.321$) displayed that far stimuli (MEAN= 743.741 ms, SD= 140.503 ms) had faster latencies than near stimuli (MEAN= 870.216 ms, SD= 180.676 ms): $p^{\text{holm}} < .001$, MD= -109.254 ms.

RTs results are plotted in Figure 54 and Figure 55.

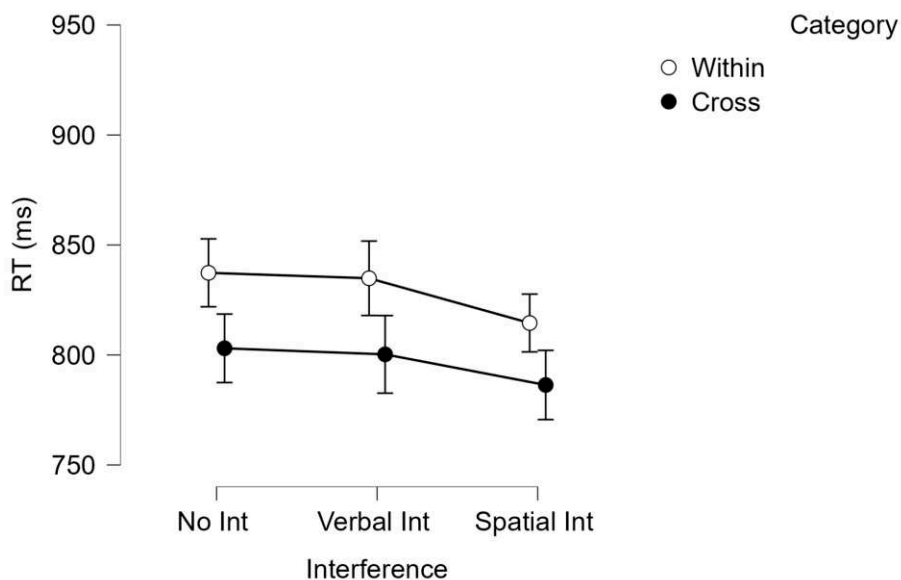


Figure 54: Reaction Times (in ms) for within and cross-category stimuli in the three interference blocks, for French monolinguals, with Standard Error (SE) bars.

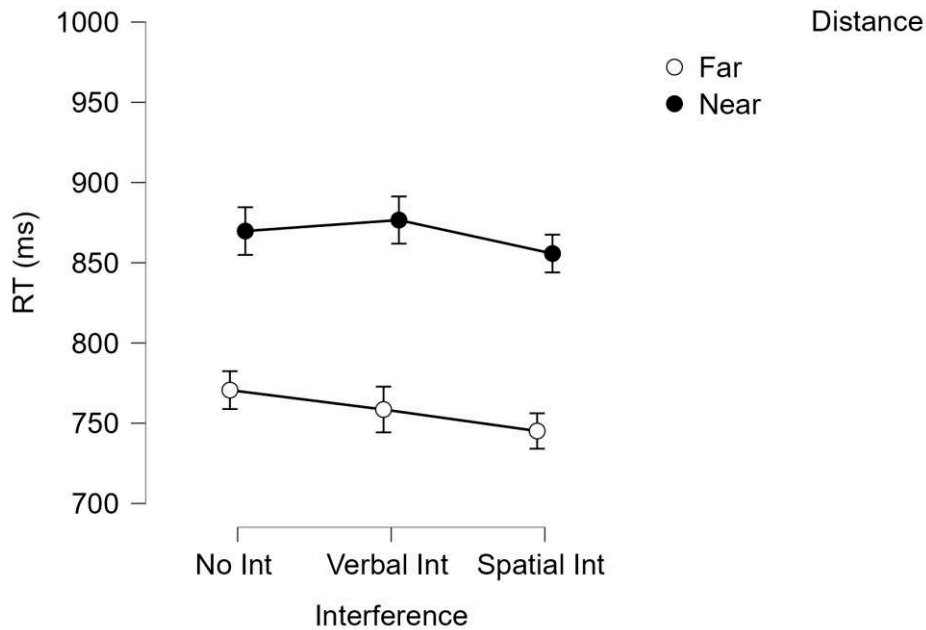


Figure 55: Reaction Times (in ms) for far and near colours stimuli in the three interference blocks, for French monolinguals, with Standard Error (SE) bars.

In the analysis of error rates, Post Hoc tests revealed distributions for the Category effect ($F(1, 21) = 9.529$, $MSE = 74.103$, $p = 0.006$, $\eta^2 = 0.016$) and for the Distance effect ($F(1, 21) = 73.568$, $MSE = 246.794$, $p < .001$, $\eta^2 = 0.418$). Even for accuracy, Post Hoc statistical tests attested that responses for within-category trials (MEAN= 81.157%, SD= 9.893%) are more accurate than responses for cross-category trials (MEAN= 81.402%, SD= 12.288%): $p^{\text{holm}} = 0.006$, MD= 3.271%. Moreover, far colours discriminations (MEAN= 88.839%, SD= 11.133%) are more accurate than near colours discriminations (MEAN= 72.253%, SD= 12.379%): $p^{\text{holm}} < .001$, MD= 16.586%. These results are illustrated in Figure 56 and Figure 57.

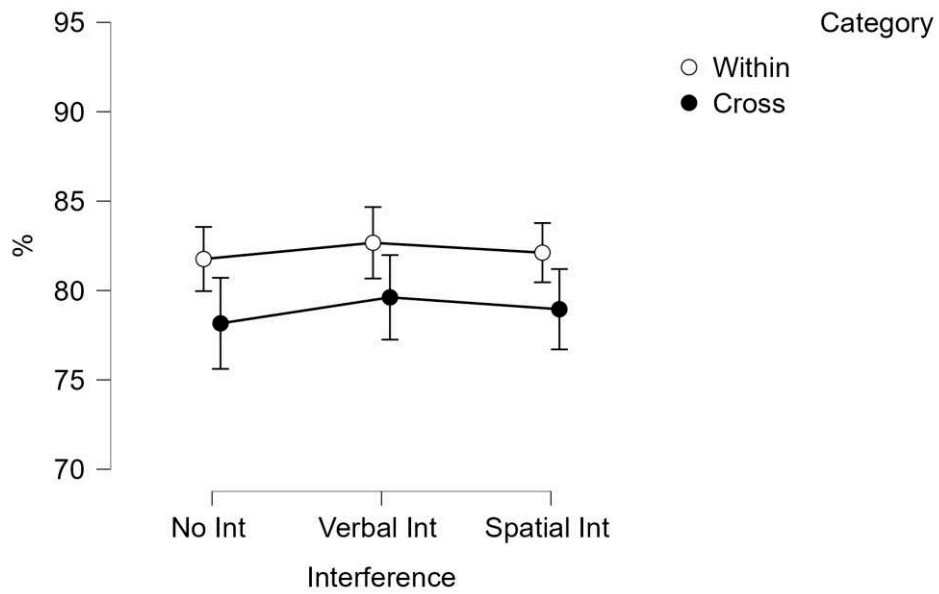


Figure 56: Accuracy (in percentage) for within and cross-category trials in the three interference blocks, for French monolingual speakers, with Standard Error (SE) bars.

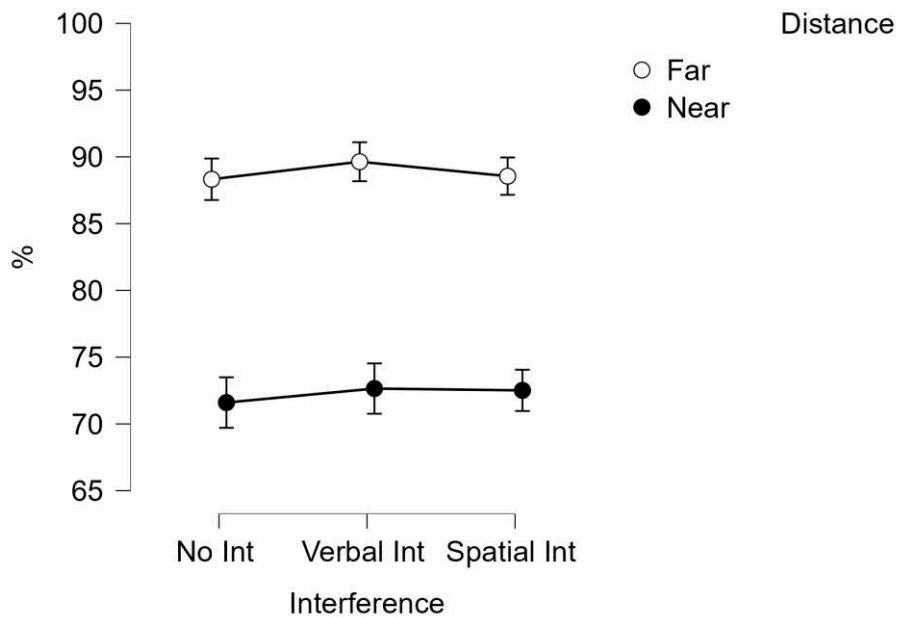


Figure 57: Accuracy (in percentage) for far-near stimuli in the three interference blocks, for French monolingual speakers, with Standard Error (SE) bars.

d. Discussion

French speakers' data analysis attested that a Category Advantage emerges without any distinction of experimental block with far colours more rapidly and accurately discriminated. These unexpected results can be explained by a meaningful perceptual difference between dark blue hues and light blue hues in French, which is indirectly reflected in perceptual tasks but not in lexical distinct categories. Prototypicality of the blue color, as well as consensus naming, can give additional information about the perceptual processing of dark blue and light blue by French speakers.

4.1.2.2.1.2 The Italian Subjects

c. Behavioural analysis

ANOVA (2 X 3 X 2) measures showed an effect of Distance for reaction times and accuracy in Italian monolinguals (N= 22).

For the RTs Distance effect ($F(1, 20) = 163.693$, $MSE = 12362.814$, $p < .001$, $\eta^2 = 0.546$), a Post Hoc test ($p^{\text{holm}} < .001$) revealed that far colours discriminations (MEAN= 744.057 ms, SD= 94.698 ms) are 179.227 ms faster than near colours discriminations (MEAN= 912.047 ms, SD= 143.605 ms); whereas Post Hoc test for accuracy of the Distance effect ($F(1, 21) = 114.845$, $MSE = 74.230$, $p < .001$, $\eta^2 = 0.360$) demonstrated that far colours discriminations (MEAN= 98.137%, SD= 1.888%) are more accurate than near colours discriminations (MEAN= 86.772%, SD= 5.457%) in all the experimental blocks: $p^{\text{holm}} < .001$, MD= 11.365%.

Figure 58 and Figure 59 illustrate these two effects.

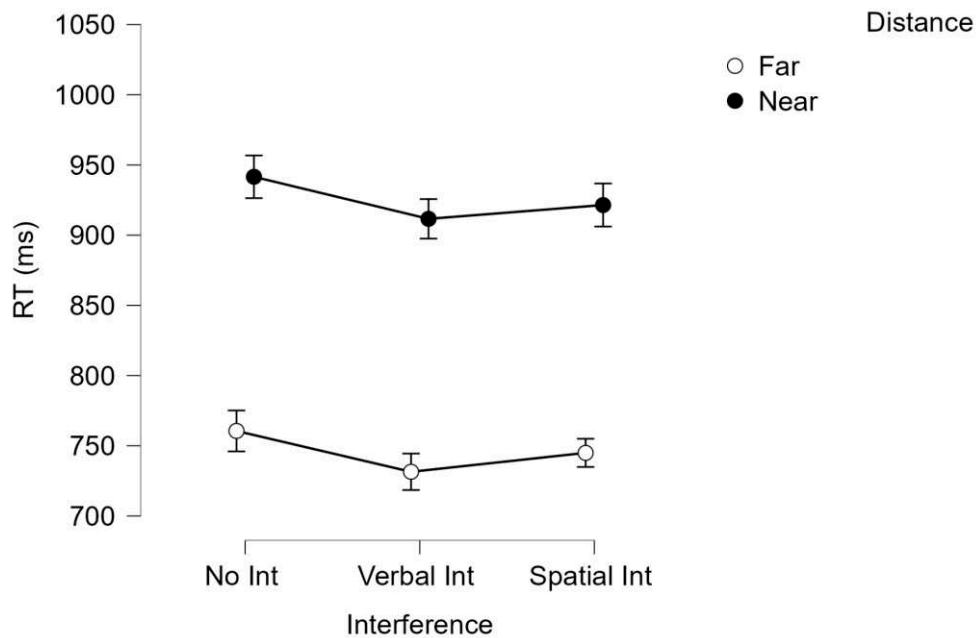


Figure 58: Reaction times (in milliseconds) for far-near stimuli in the three interference blocks, for Italian monolingual speakers, with Standard Error (SE) bars.

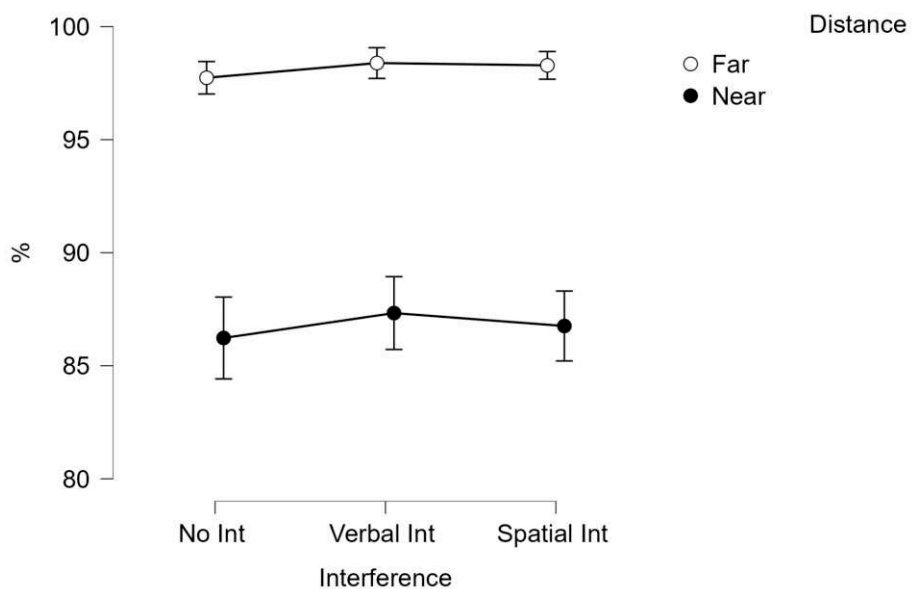


Figure 59: Accuracy (in percentage) for far-near stimuli in the three interference blocks, for Italian monolingual speakers, with Standard Error (SE) bars.

Furthermore, we can mention a tendency for reaction time in the interaction between Category and Distance ($F(1, 20) = 3.483$, $MSE = 3980.927$, $p = 0.077$, $\eta^2 = 0.004$) which

revealed that the Distance factor is always dominant on the Category factor: far color stimuli are, in fact, always discriminated faster in all category condition, even in within-category trials compared to near colours discrimination in cross-category trials ($p^{\text{holm}} < .001$, MD= -173.149 ms).

d. Discussion

Italian data showed that there does not exist a category advantage for this group of speakers. We obtained statistically significant results only for latencies and accuracy of easier discriminations of perceptually similar stimuli in the three interference blocks, as compared to finer discriminations where trials are perceptually distant.

However, even though a category effect is statistically absent, we found that it is descriptively salient, validating our original hypothesis. This aspect will be discussed in the next section of this chapter about results' interpretation.

4.1.2.2.2 The French-Italian Bilingual Speakers

c. Behavioural analysis

French-Italian bilinguals' ANOVA analyses (Figure 61) revealed an effect of distance ($F(1, 19) = 128.332$, $MSE = 12640.328$, $p < .001$, $\eta^2 = 0.497$) and two double interactions, one Interference X Category ($F(2, 38) = 3.511$, $MSE = 4589.236$, $p = 0.040$, $\eta^2 = 0.010$) and one Interference X Distance ($F(2, 38) = 4.519$, $MSE = 3027.445$, $p = 0.017$, $\eta^2 = 0.008$), for reaction times.

Post Hoc test for the Distance Effect showed that, even for bilingual speakers, far colours (MEAN= 834.246ms, SD= 112.472ms) were discriminated 164.426 ms faster than near colours (MEAN= 983.561 ms, SD= 129.206 ms): $p^{\text{holm}} < .001$. Furthermore, the two interactions have reported a statistically significant effect of far colours stimuli ($p < .001$)

in the three experimental blocks compared to near colours trials, as well as a salient impact of category on the Verbal Interference Block ($p= 0.018$).

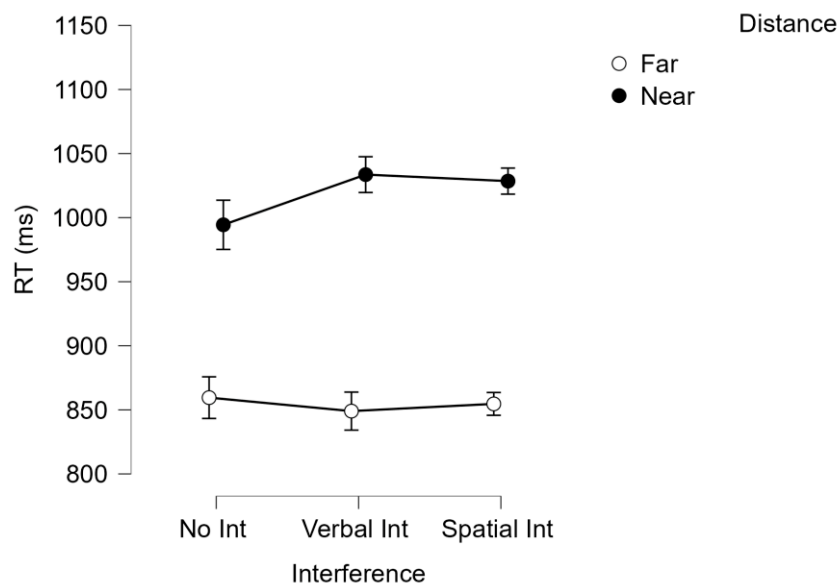


Figure 60: Reaction times (in milliseconds) for far-near stimuli in the three interference blocks, for French-Italian bilingual speakers, with Standard Error (SE) bars.

In the analysis of error rates, we obtained a Category effect ($F(1, 19) = 9.033$, $MSE = 112.671$, $p = 0.007$, $\eta^2 = 0.020$) and a Distance effect ($F(1, 19) = 168.680$, $MSE = 126.727$, $p < .001$, $\eta^2 = 0.429$). As for the other participants' groups, Post Hoc statistics attested that responses for far colours discriminations (MEAN= 90.514%, SD= 7.571%) are more accurate than near colours discriminations (MEAN= 71.639%, SD= 11.239%): $p^{\text{holm}} < .001$, MD= 18.875%. At the same time, Post Hoc distributional analysis for category showed that bilinguals are less accurate for within-category trials (MEAN= 81.291%, SD= 8.795%) than for cross-category trials (MEAN= 82.585%, SD= 9.290%): $p^{\text{holm}} = 0.007$, MD= 4.119%.

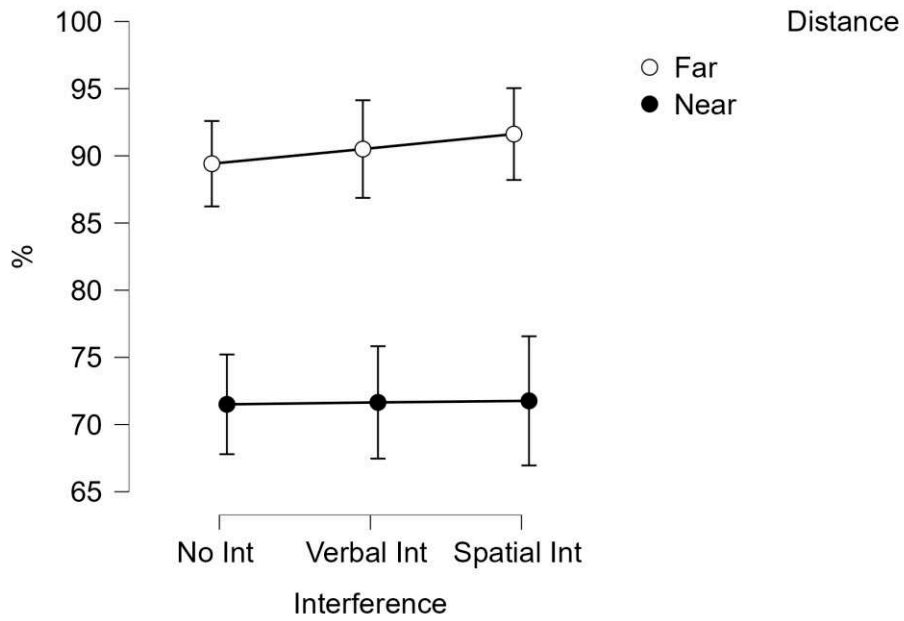


Figure 61: Accuracy (in percentage) for far-near stimuli in the three interference blocks, for bilingual speakers, with Standard Error (SE) bars.

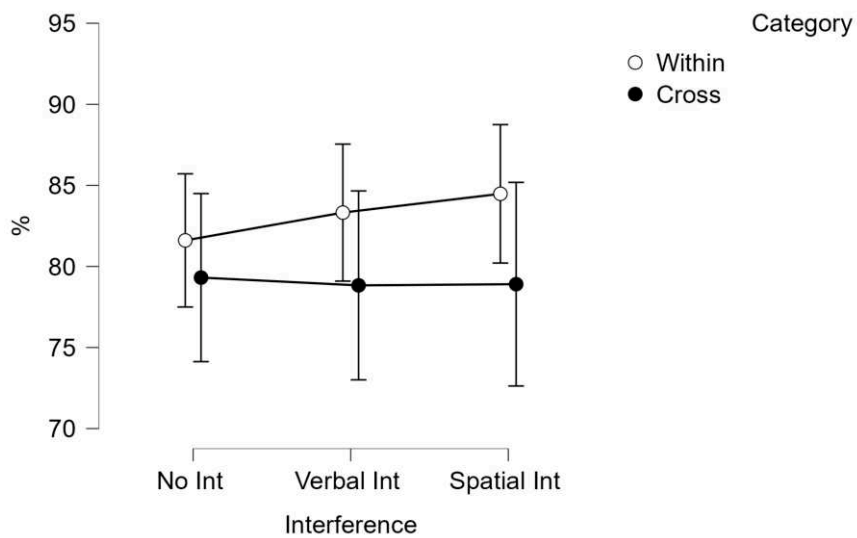


Figure 62: Accuracy (in percentage) for within and cross-category trials in the three interference blocks, for bilingual speakers, with Standard Error (SE) bars.

d. Discussion

French-Italian bilinguals' data reported heterogeneous statistical results: the advantage of category we supposed to observe was not found. The only exception was data coming from the experimental block without interference for near color stimuli and for the verbal interference block for far color stimuli, which were relevant. In fact, cognitive charges can influence bilinguals' performances on a double task relying on two different category systems of their L1 and L2: patches perceptually similar and patches perceptually distant are not processed in very distinct ways.

We will discuss in detail the results' interpretation in the next section of this chapter.

4.1.2.2.3 Between-Groups Comparison

b. Behavioural analysis

A between-subjects comparison has been performed to understand the possible impact of different participants' groups on the Category Advantage: we, thus, added the Group, as a between-subject factor, to the previous three-ways ANOVA (2 X 3 X 2), where repeated-measures factors were Interference, Category and Distance.

For Reaction Times analysis, we obtained a Category effect ($F(1, 60) = 56.719$, $MSE = 203295.548$, $p < .001$, $\eta^2 = 0.021$) and a Group effect ($F(2, 60) = 4.851$, $MSE = 111691.522$, $p = 0.011$, $\eta^2 = 0.112$). The Post Hoc test we performed for the Category effect revealed that within-category trials (MEAN= 872.788ms, SD= 151.328ms) are discriminated 46.417ms slower than cross-category trials (MEAN= 854.010ms, SD= 155.792ms): $p^{\text{holm}} < .001$; whereas the Post Hoc test for RTs distributions depending on groups showed that bilinguals are globally the slowest ones, without distinction of interference conditions. Bilingual latencies are, in fact, slower than French reaction times ($p^{\text{holm}} = 0.017$, MD= 122.439 ms) and than Italian reaction times ($p^{\text{holm}} = 0.029$, MD= 106.152 ms), as plotted in Figure 63.

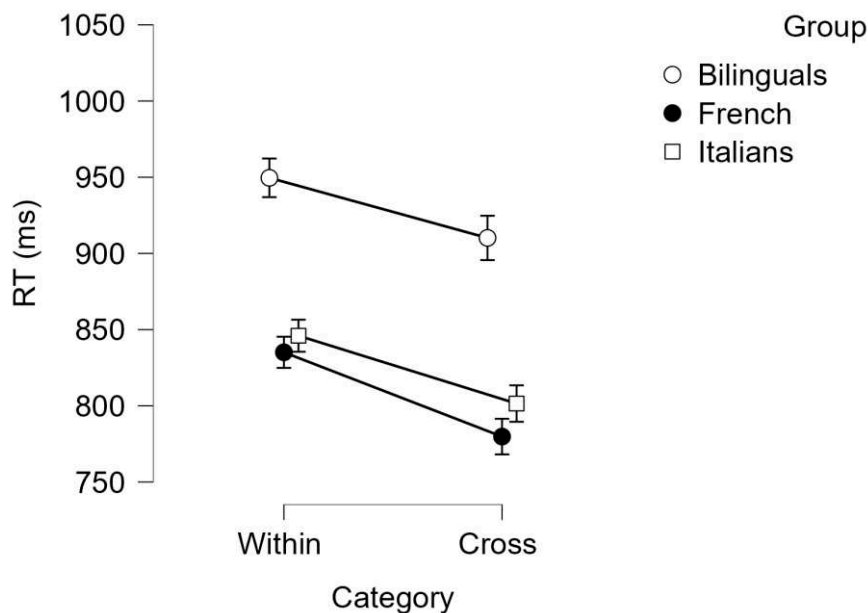


Figure 63: RT Latencies (in ms) for within and cross-category trials in the three participants' groups, with Standard Error (SE) bars.

ANOVA results for accuracy, have revealed the emergence of a Category effect ($F(1, 61) = 18.092$, $MSE = 1552.018$, $p < .001$, $\eta^2 = 0.008$), a Distance effect ($F(1, 61) = 311.244$, $MSE = 46683.187$, $p < .001$, $\eta^2 = 0.243$), as well as a Group effect ($F(2, 61) = 14.123$, $MSE = 834.625$, $p < .001$, $\eta^2 = 0.123$). We performed several Post Hoc tests to analyse the distributions of each effect. Statistics demonstrated that cross-category trials (MEAN= 86.095%, SD= 10.741%) are better discriminated ($p^{\text{holm}} < .001$, MD= 2.846%) than within-category trials (MEAN= 85.039%, SD= 9.311%), as well as far color stimuli (MEAN= 92.559%, SD= 8.765%) have responses more accurate than near color stimuli (MEAN= 77.052%, SD= 12.225%): $p^{\text{holm}} < .001$, MD= 15.609%.

Moreover, group interaction is statistically significant especially in the comparison between bilinguals and Italian monolinguals ($p^{\text{holm}} < .001$, MD= -11.378%) and between French monolinguals vs. Italian monolinguals ($p^{\text{holm}} < .001$, MD= -11.909%). Bilingual speakers, in fact, made more errors than Italian speakers who resulted to be the more accurate group, even compared to French speakers.

Accuracy results are plotted in Figure 64 and Figure 65.

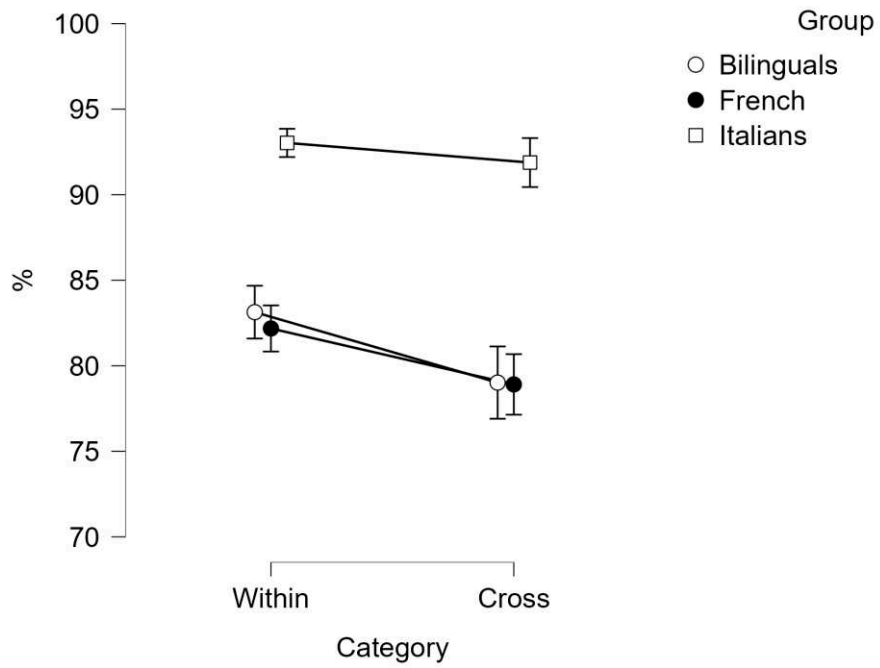


Figure 64: Accuracy (in percentage) for within and cross-category trials in the three participants' groups, with Standard Error (SE) bars.

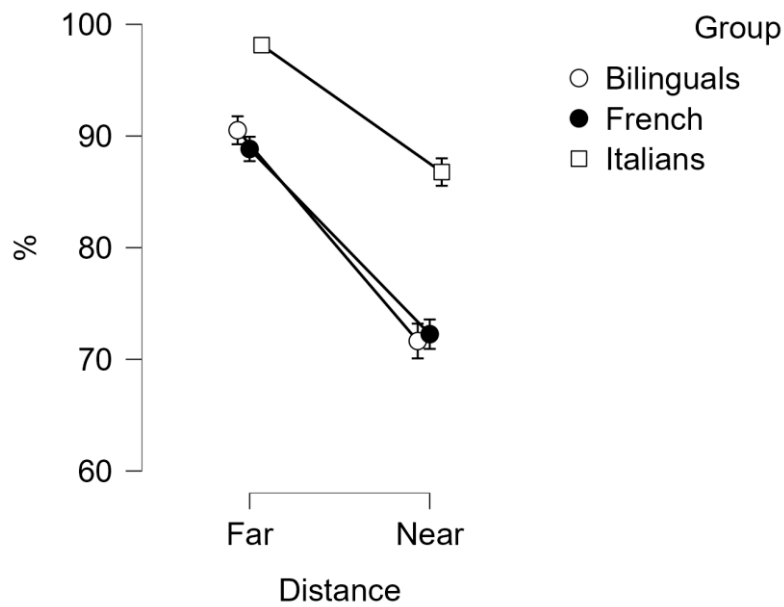


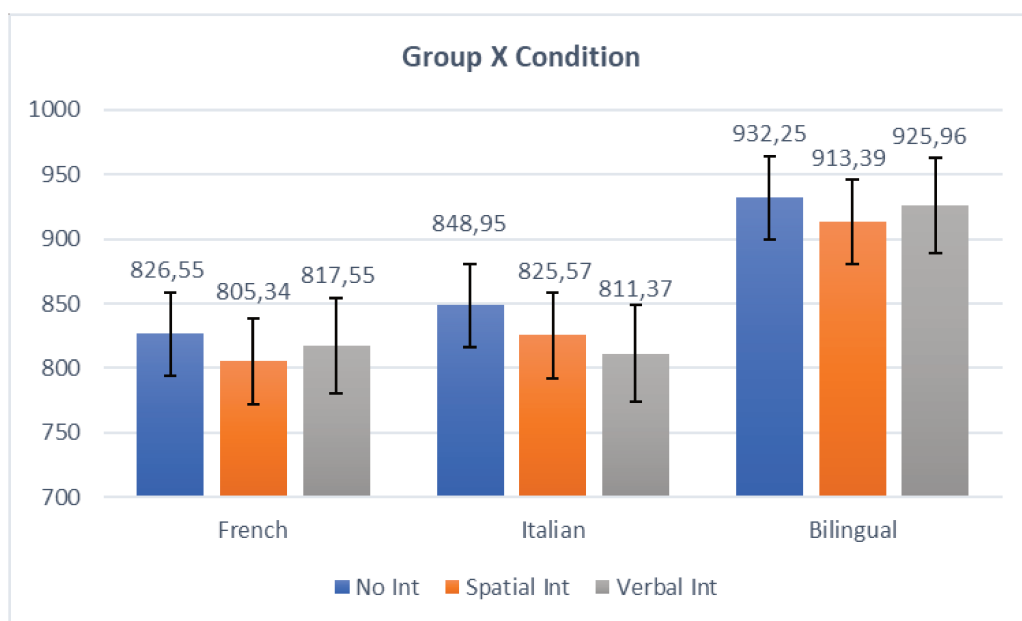
Figure 65: Accuracy (in percentage) for far and near stimuli in the three participants' groups, with Standard Error (SE) bars.

b. Discussion

In the between-group comparison analysis we did not find any Category Advantage. In fact, all the statistically relevant results we obtained reflect similar data coming from within-subjects comparisons. Thus, the group factor does not have any impact on the interaction between distance, interference and category.

French, Italian and bilingual speakers behave in different ways, even though some perceptual aspects are similarly processed. Once more, it is relevant to highlight the global slowness and inaccuracy of the bilingual group compared to the two other monolinguals due all the cognitive costs we have already mentioned above, as shown in the literature (Gollan, Montoya and Werner 2002).

To conclude this section, we graphically report the differences in performances for the Speeded Color Discrimination Task for the three groups of participants in the three experimental conditions in order to have a greater portrait of the discrepancies in reaction times between speakers.



Graph 5: Global mean reaction time (in milliseconds) for the three participants' groups in the three Experimental conditions, with Standard Error (SE) bars.

4.1.2.3 Analysis of the Interference Stimuli Results

a. Behavioural analysis

The last analysis we performed for the Speeded Color Discrimination Task concerns the two kinds of interference, the verbal and the spatial ones. We conducted a two-way repeated-measures ANOVA for reaction times and accuracy where Interference was the repeated measure factor and Group was the between-subject factor (ANOVA 2 X 3). For all the groups (N= 66), we excluded 7% of incorrect responses, as well as a total 1.5% of individual outliers per participant, too.

We obtained an effect of Interference ($F(1, 61) = 31.130$, $MSE = 2457000$, $p < .001$, $\eta^2 = 0.181$) for reaction times and for accuracy ($F(1, 61) = 4.342$, $MSE = 205.340$, $p = 0.041$, $\eta^2 = 0.032$). Post Hoc test for RTs distributions showed that verbal interference stimuli were globally discriminated 277.367 ms faster ($p^{\text{holm}} < .001$) but 2.536% less accurately ($p^{\text{holm}} = 0.041$) than spatial interference stimuli. Details about mean and standard deviation are reported in Table 6, whereas Interference effects for latencies and accuracy for the three groups of participants are illustrated in Figure 66 and Figure 67.

	REACTION TIME		ACCURACY	
	Verbal Interference	Spatial Interference	Verbal Interference	Spatial Interference
MEAN	895.458	1172.825	13.690	16.226
SD	67.603	61.198	0.659	1.231

Table 6: Average means and standard deviation for Reaction Times (in ms) and Accuracy (in %) for verbal and spatial interference stimuli.

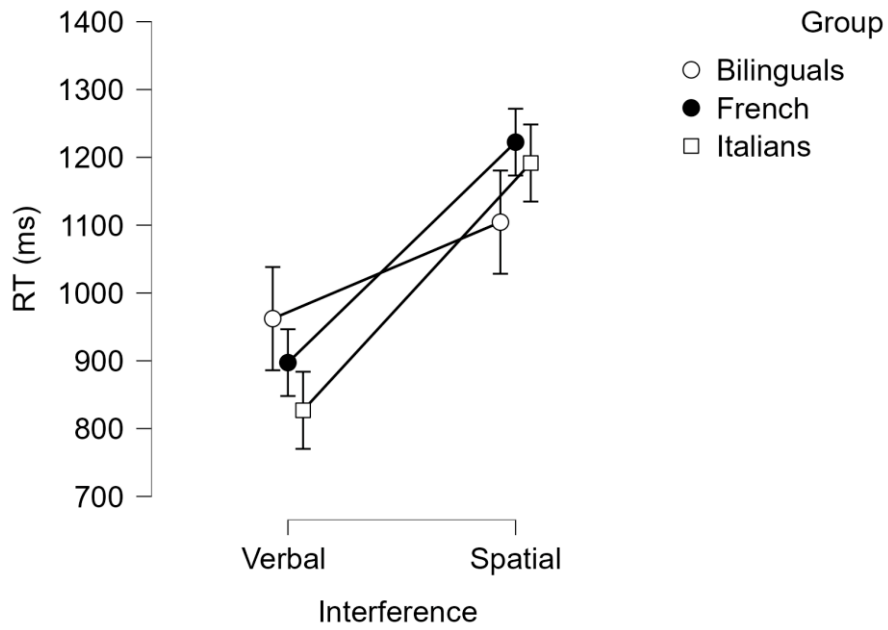


Figure 66: Reaction times (in milliseconds) for verbal and spatial interference stimuli for the three groups of participants, with Standard Error (SE) bars.

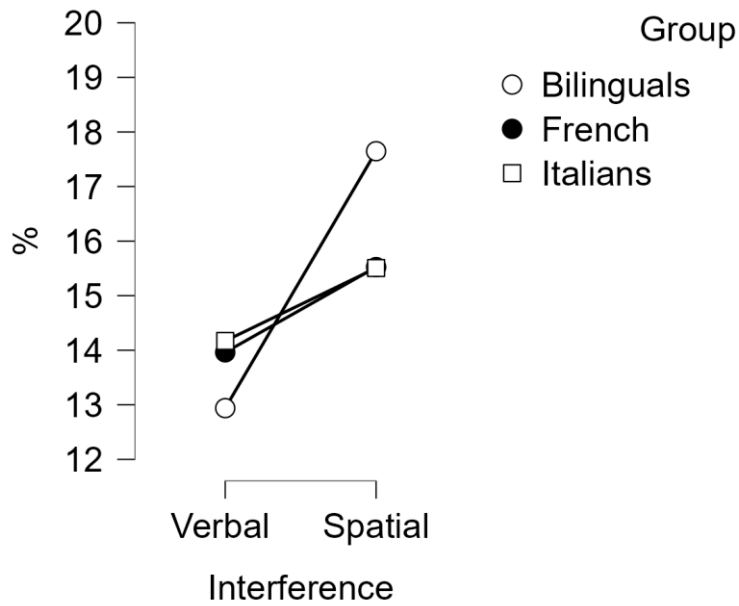


Figure 67: Accuracy (in percentage) for verbal and spatial interference stimuli for the three groups of participants.

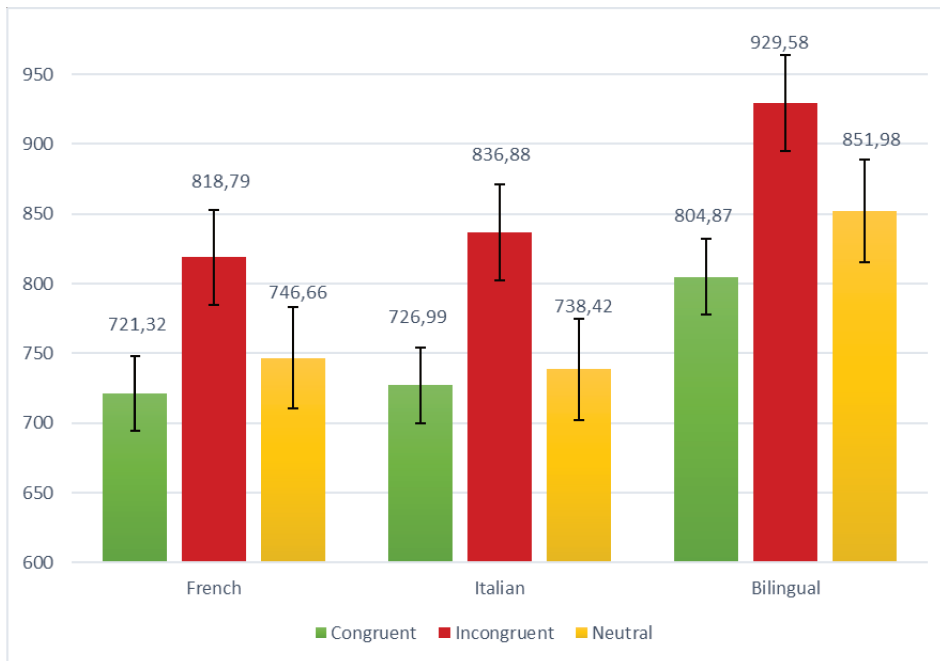
b. Discussion

Statistics for verbal interference stimuli and spatial interference stimuli showed that the group of speakers did not impact performances on interference stimuli: French, Italian and bilingual speakers behave similarly. However, color words stimuli (Verbal Interference) are rehearsed more easily, leading to faster latencies of response, but are subject to more errors than black-white grids (Spatial Interference) where spatial memory plays a central role of facilitation during a perceptual task.

4.2 Global results' discussion

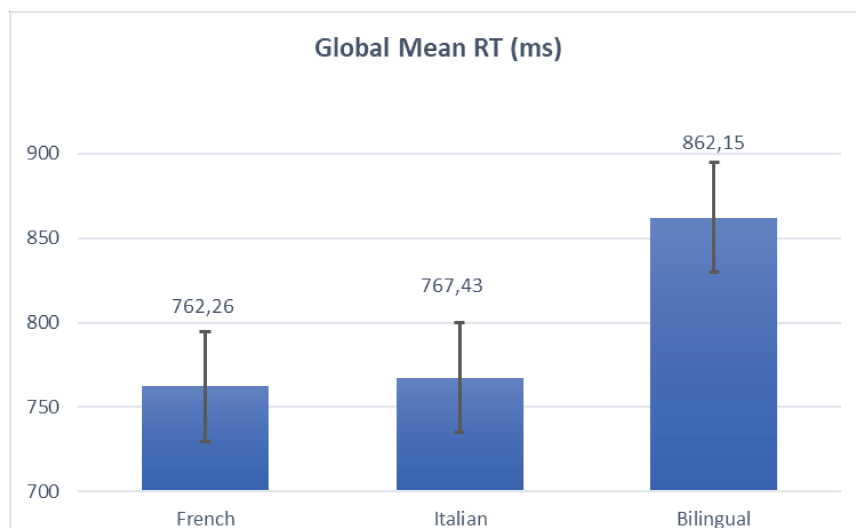
In the last section of this chapter, we will discuss the results of the current study, explaining the interpretation we made about statistical data which validate or not our hypotheses.

The Color Word Stroop Task results have globally validated our hypothesis about the emergence of a Stroop Effect: we recorded differences in latencies for congruent stimuli compared to incongruent and neutral stimuli, in all the three participants' groups. As plotted in Graph 6, matching color ink- color word stimuli are the fastest discriminated ones.

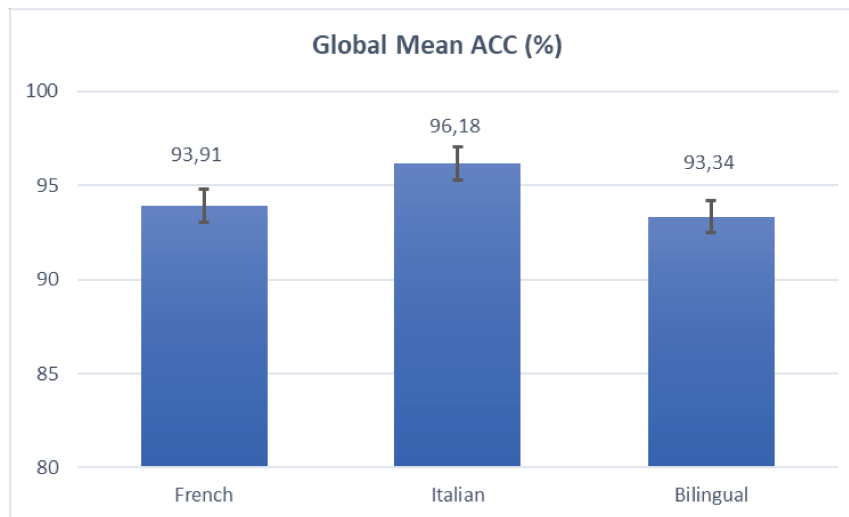


Graph 6: The Stroop Effect (mean reaction times in milliseconds) in the three groups of participants for each congruency condition with Standard Error (SE) bars.

However, bilingual overall performances are the slowest compared to French and Italian monolingual speakers, as we can see in Graph 7. This is probably due to delays in the inhibition of one lexical and conceptual system, as well as to cognitive costs, like decision making and pre-attentive processes, acting in mastering more than one language.



Graph 7: Global mean reaction times (in milliseconds) for the Stroop Effect for the three groups of speakers with Standard Error (SE) bars.



Graph 8: Global mean Accuracy (in percentage) for the Stroop Effect for the three groups of speakers with Standard Error (SE) bars.

Moreover, analysing in detail the Stroop Effect for the blue color words *bleu* and *blu* we found unexpected results for French speakers. They were supposed to show a standard Stroop Effect for blue colours stimuli (**Bleu** / **Bleu**), or that **Bleu** stimuli were discriminated faster than **Bleu** stimuli, or even that there would be uniformity in the detection of **Bleu** and **Bleu** stimuli. Since they lack a lexical distinction between the two colour categories, no salient difference would be expected.

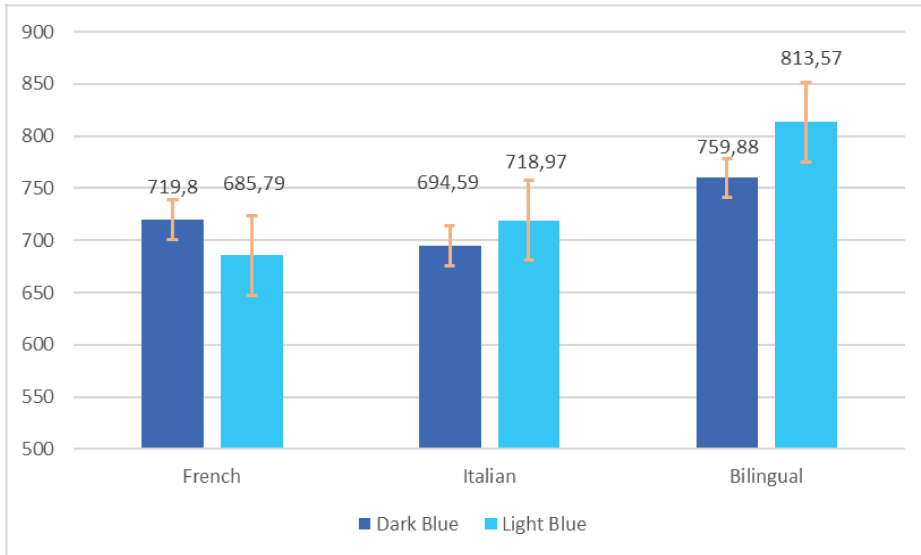
Statistical data, in contrast, attested the opposite trend: as we mentioned above, their major rapidity in incongruent stimuli discrimination could be explained by the chromaticity, as well as the degree of saturation, of the dark blue and the light blue in French. French speakers have probably a higher consensus on color foci for light blue as compared to color foci for dark blue: this factor leads to a form of prototypicality of the light hue, thus to different reaction times.

In contrast, statistical results for Italian and bilingual speakers validated our hypotheses: Italians are more rapid for **Blu** stimuli as compared to the incongruent **Blu** stimuli since the two inks are tied to two different basic color categories and to their corresponding color words (*blu* and *azzurro*). Therefore, when the word *blu* is printed in light blue hues, a perceptual conflict arises. This phenomenon allows us to bring additional relevance to the theory assuming that in Italian *azzurro* is the 12th BCT and that lexical distinctions can have an influence on perception, notably color perception.

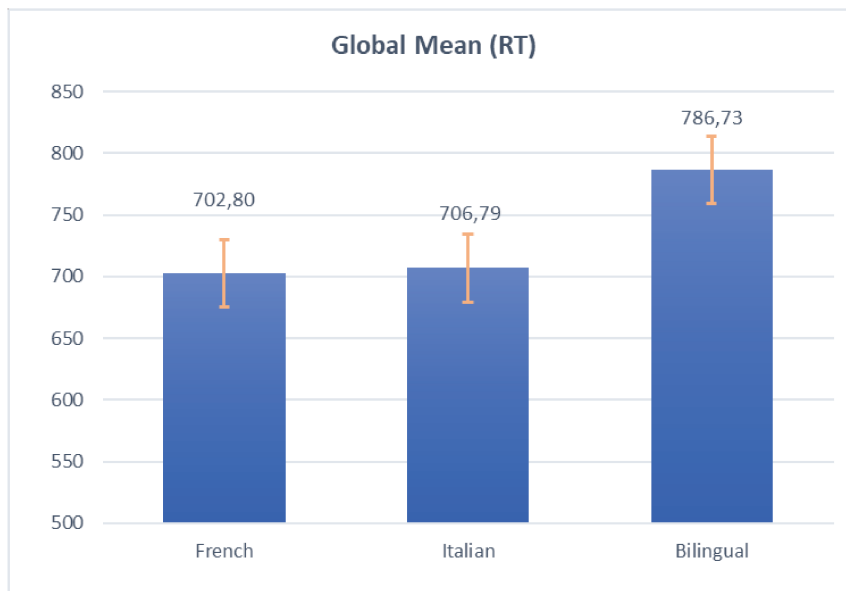
However, linguistic influences are not the only mechanisms impacting perception: cognitive factors, like pre-attentive top-down modulations, in fact, directly act during the recognition of a color stimulus. The two components cannot be discerned since they operate together in chromatic perception.

Bilingual speakers showed similar results to Italian monolingual speakers: all the blue color words, both in French and in Italian (*bleu* and *blu*), are processed in the same way: **Bleu** and **Blu** stimuli are discriminated faster than **Bleu** and **Blu**. In addition, reactions to Italian color words are faster than to French color words. These expected effects bring further evidence to the impact of lexical categories on color perception and attest the adoption of the L2 conceptual system. Their proficiency in Italian leads them to behave like their corresponding Italian monolingual speakers even when stimuli are presented in another language and in fully perceptual tasks. This aspect is explained by the assumption that, once they have completely acquired and interiorized a lexical system categorizing in a different way, they would use this conceptualisation even though it does not belong to their first language (French), the most dominant one, with another type of categorization. As a consequence, in the bilingual mind there is a sort of irreversible mechanism which acts in all circumstances in various tasks, showing that language has a great impact on several cognitive domains.

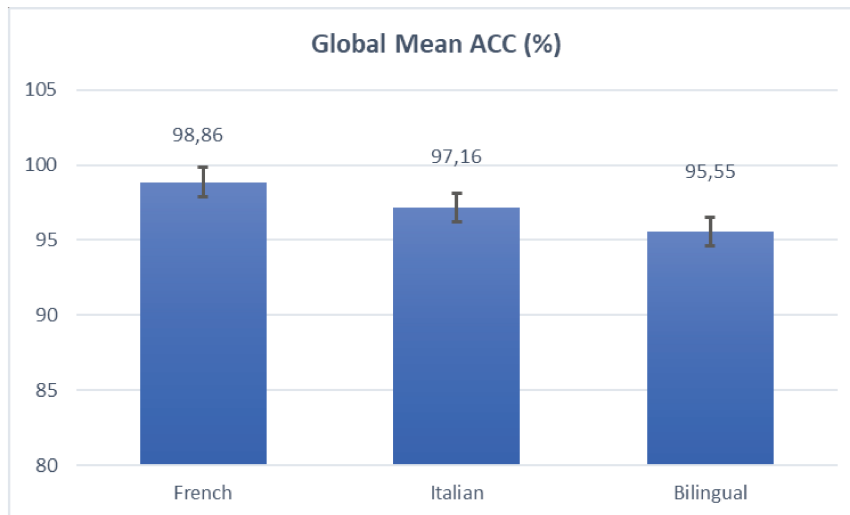
Our group of adult proficient French-Italian bilinguals does not make any distinction between French and Italian color words, processing them with Italian lexical and perceptual categories. This aspect is another empirical proof of the status of the color word *azzurro*, as well as the different color boundaries in the blue spectrum in Italian language.



Graph 9: The Blue Color Word Effect (mean reaction times in milliseconds) in the three groups of participants for each congruency condition with Standard Error (SE) bars.



Graph 10: Global mean reaction times (in milliseconds) for the Blue Color Word Effect for the three groups of speakers with Standard Error (SE) bars.



Graph 11: Global mean Accuracy (in percentage) for the Blue Color Word Effect for the three groups of speakers with Standard Error (SE) bars.

Results from the Speeded Color Discrimination Task showed heterogeneous behaviours, whose interpretation partially confirms some of our original hypotheses and, at the same time, revealed new unexpected factors which don't corroborate our assumptions.

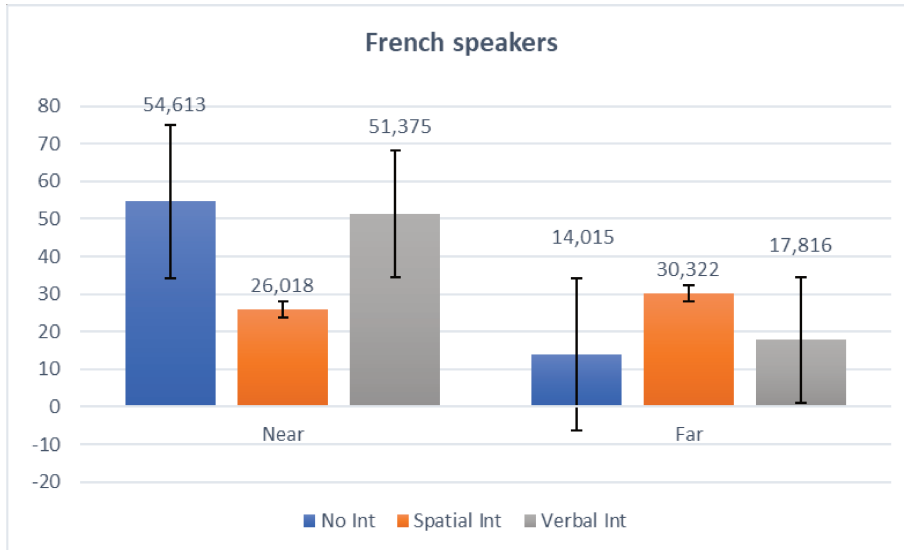
For the differences linked to experimental squares' color, dark blue and light blue patches, the main results are the faster discrimination of far colours stimuli compared to near colours stimuli for all the participants, as well as the discrepancies in reaction times between BLU patches and AZZURRO patches. If the French group is more rapid for dark blue hues, Italians are more rapid for light blue hues. The two cases were expected: for French, in fact, the rapidity can be explained by the *bleu* focal color which corresponds to a dark blue nuance. In contrast, for Italian subjects, the major rapidity can be due to the basicness of the color word *azzurro*, which has the same status as the color word *blu*, creating an equal competition between the two colour categories they linguistically designate. This aspect corroborates the hypothesis that, in Italian, the blue chromatic spectrum is differentiated in two different categories based on lightness, which receive general naming consensus and are perceived equally solid and salient. The two colours (dark and light blue) have, thus, a high degree of chromaticity which implies a stronger and more stable category boundary.

The last group, the bilingual one, behaves like French monolingual speakers: this result can be associated with the stability of the dark blue category in the double simultaneous lexical and conceptual system in the bilingual mind. In fact, since the dark blue color category is considered a basic category both in French and in Italian, French-Italian bilinguals probably perceive this category as being a little more stable or it is simply the one they use to face the most, since it is shared by French and Italian. As a consequence, their performances are faster for BLU patches than for AZZURRO patches; they, thus, behave differently but not deficiently.

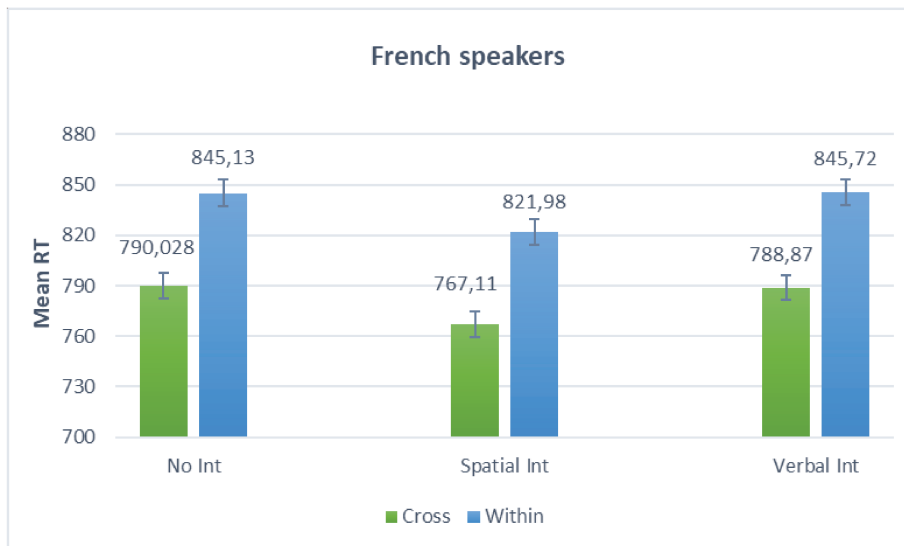
The results on the Category Advantage (CA) are particularly discordant with our hypotheses, as well as with Winawer's results.

Firstly, we did not obtain a CA for our Italian monolinguals, corresponding to the Russian speakers of Winawer's study. On the contrary, French monolingual speakers, corresponding to the English control group of Winawer, showed a CA in all the experimental conditions (no interference block, verbal interference block and spatial interference block) both for near and far color pairs. However, the effect was more salient for far color stimuli.

French speakers are, thus, faster in cross-category trials, without any distinction of condition: this reflects the absence of a direct influence of lexical categories on color perception since French lacks the linguistic distinction between the two blue hues, validating our hypothesis. Thus, as illustrated in Graph 12, the French group is the most homogeneous one.



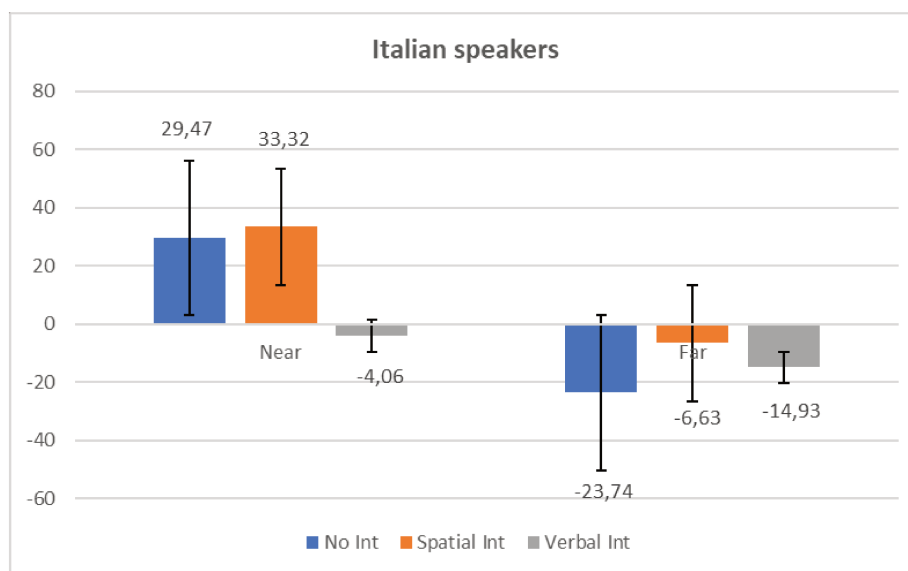
Graph 12: Category Advantage for French speakers: mean reaction time (in milliseconds) for the interaction between distance and interference condition with Standard Error (SE) bars.



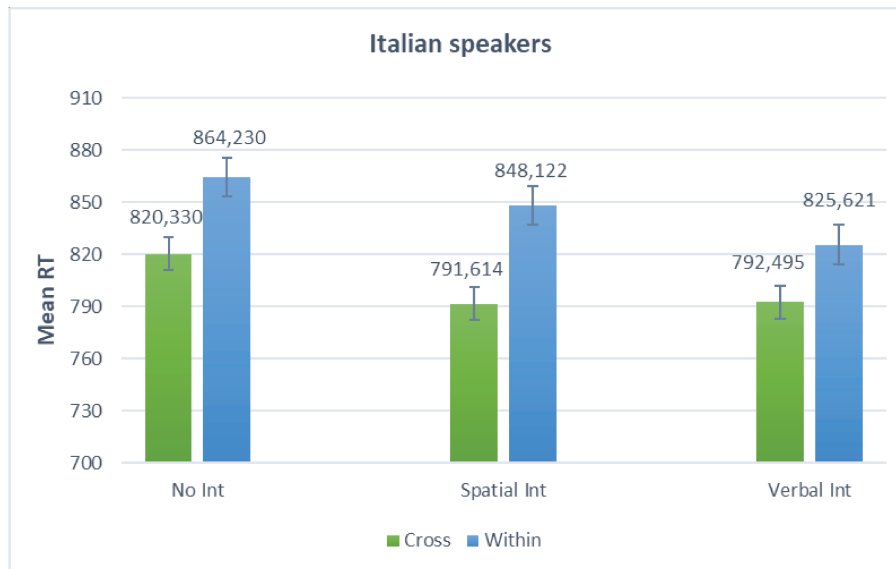
Graph 13: Mean reaction time (in milliseconds) for the two-way interaction between category and interference condition with Standard Error (SE) bars for French speakers.

For Italian and French-Italian bilingual speakers, we obtained completely unexpected results.

For Italians, we had a Category Advantage only from a descriptive, but not from a statistical, point of view: as we can see in Graph 14, in fact, there is an advantage for cross-category trials in the No Interference block and in the Spatial Interference block, but not in the Verbal Interference block, which corresponds to our hypotheses. However, this effect is not statistically significant. At the same time, for far color stimuli, they are more rapid in within-category colours (falling under the *blu* or *azzurro* label): the distance has, thus, a more dominant role compared to category for these speakers.



Graph 14: Category Advantage for Italian speakers: mean reaction time (in milliseconds) for the interaction between distance and interference condition with Standard Error (SE) bars.



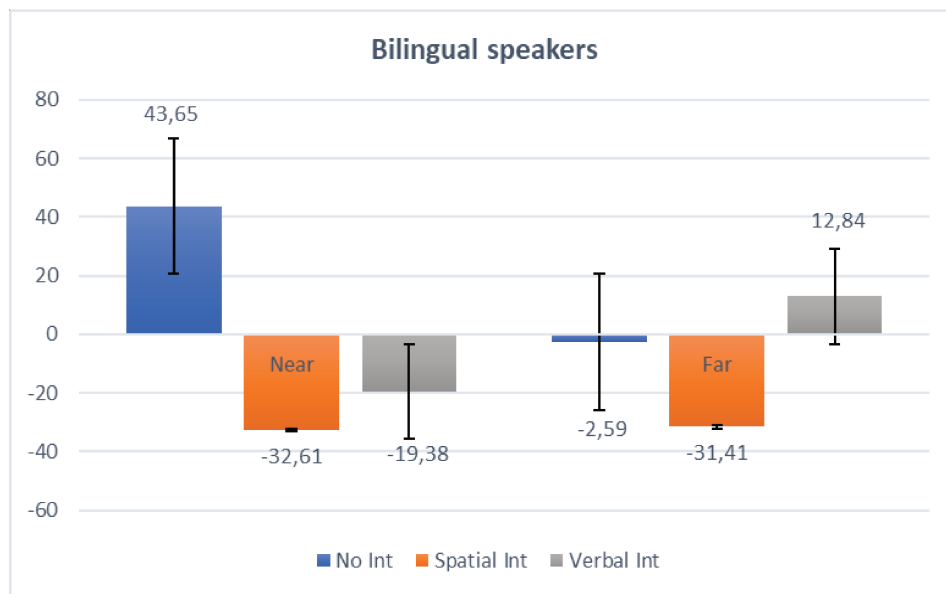
Graph 15: Mean reaction time (in milliseconds) for the two-way interaction between category and interference condition with Standard Error (SE) bars for Italian speakers.

At the same time, bilinguals revealed a CA only for near color stimuli in the No Interference block, which is the only condition where we find it, as plotted in Graph 16. In all the other conditions we have detected faster latencies for within-category trials compared to cross-category trials in near and far stimuli, except for the verbal interference block where there is a category advantage for far stimuli. These data do not, thus, correspond to our hypothesis of attending a CA for near color stimuli in cross-category trials in the spatial interference block and in the block without interference, but not in the verbal interference block due to an online direct impact of language on perception.

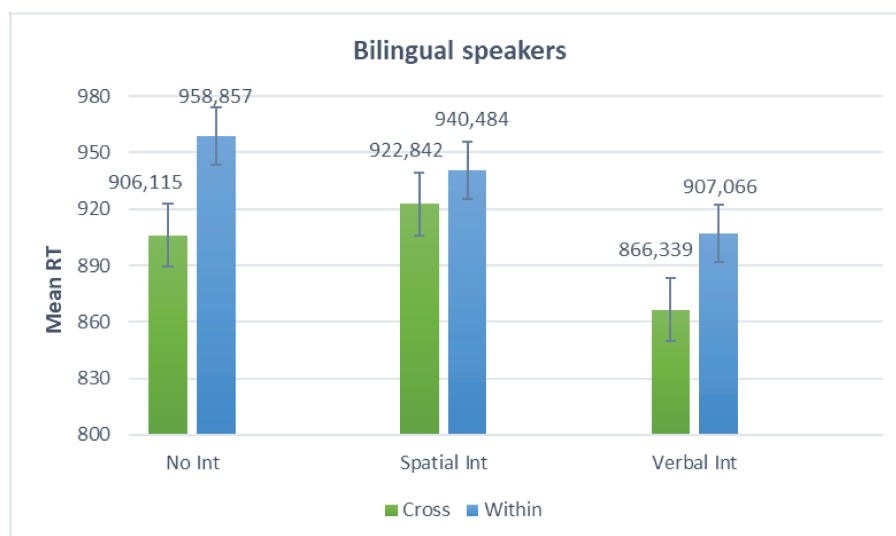
The outcomes can be explained by the cognitive costs of bilingual speakers which play a more determinant role in color perception than expected. Cognitive functions probably modulate visual decisions in perceptual tasks where a judgment is required, notably in speakers whose linguistic system has more than one stable color category in a specific area of the color spectrum, like Italian. In this case, in fact, visual, lexical and cognitive conflicts can take place simultaneously during the simple perception of a color stimulus.

If we compare the three Graphs (12, 14 and 16) it is evident that French subjects behave in a unique way which is not found elsewhere, whereas there exists a common thread

between Italian and French-Italian bilinguals, despite the differences. Starting from these similarities, further deeper analyses are required to understand the individual top-down modulation of cognitive functions, as well as their interconnection with the online impact of language.



Graph 16: Category Advantage for bilingual speakers: mean reaction time (in milliseconds) for the interaction between distance and interference condition with Standard Error (SE) bars.



Graph 17: Mean reaction time (in milliseconds) for the two-way interaction between category and interference condition with Standard Error (SE) bars for bilingual speakers.

The last aspect worth highlighting is that bilinguals are globally slower than the two monolingual groups in all experiences. This aspect reflects some previous similar results, as those obtained by Martinovic, Paramei and their colleagues (Martinovic, Paramei, and MacInnes 2020) about latencies of bilingual speakers in perceptual tasks. As the authors explained, to access lexical categories, temporal costs are provoked by the inhibition of the off-line categorization, due to the constant parallel activation of the two language systems.

However, the constant mechanisms of inhibition they daily face allow them to have globally more accurate performances as compared to French and Italian monolinguals. The bilingual advantage we talked about in the second chapter of this PhD thesis can, in fact, appear in different forms in various perceptual tasks, like those we used in our study. Color vision is one of the perceptual domains where the impact of brain plasticity, stronger in bilingual subjects, is particularly visible.

Conclusions

In this chapter we have presented the behavioural analysis of our data set and the results obtained for both the Color Word Stroop Task and the Speeded Color Discrimination Task.

We explained the types of statistical analysis we performed for each effect we decided to explore in each speakers' group, either in within-subjects' comparisons and in between-subjects' comparisons: the Stroop Effect and the Blue Color Word Effect for the Stroop Experiment, and the Color Patch Effect and the Category Advantage for the Speeded Color Discrimination Task.

Results were detailed and discussed, showing the correlation with previous research on the same domain as well as with the hypotheses we made at the beginning of this study. Some of them validated our original hypothesis, like the emergence of a strong Stroop Effect notably for blue color stimuli, whereas others did not correspond to the experimental outcomes we expected, as for the case of the Category Advantage in Italian speakers.

We tried to give a scientifically valid explanation in order to understand our results in their entirety and extract a global portrait of the phenomenon studied. We specifically put attention on additional cognitive factors which play a dominant role in chromatic perception, highlighting that lexical categories can have only a marginal impact.

In the next chapter we will consider the limits of this PhD project, from both a theoretical and a methodological point of view, and we will examine possible future directions of our research.

PART IV: Results and Future Research Directions

Chapter 5: Our Limits and Future Perspectives

Introduction

Results about our recorded data have been analysed and discussed in the previous chapter, showing that some of our initial hypotheses have not been validated and that new additional factors had led us to unexpected conclusions.

In this last chapter of my PhD thesis manuscript, we discuss the limits of our research project, as well as our future perspectives. In the first part, we will present some theoretical and methodological aspects that could be modified or improved, approaching them from a more external point of view. Then, in the second part, we will introduce the future perspectives of our study, like the addition of supplementary experimental tasks, the neurophysiological analysis of subjects' performances, the evaluation of other types of participants, as well as the expansion of our research to other colors' phenomena.

We will end this chapter with some general conclusions.

5.1 Limits of the project

The main limits of this study concern participants' characteristics as well as some methodological aspects of our experimental protocol.

First, our bilingual group has been defined on specific features about their linguistic background which have allowed us to obtain a quite homogeneous group. However, even though they all have nearly the same proficient level in Italian, most of them have been classified as early bilinguals, whereas others have rather been classed as late bilinguals. Separating the two kinds of bilingual speakers would represent a sort of refinement which could have an impact on tasks' performances: the age of acquisition of their L2 (Italian) could perhaps determine slight changes in the way they react to perceptual stimuli of different conceptual systems.

At the same time, the number of men and women in our groups of speakers should be more balanced. In each group we have a more significant percentage of women due to

recruitment availability: in fact, gender can, in color vision judgment tasks, play a quite significant role, especially in hue preferences like some research has shown (Al-Rasheed 2015). It has been attested that women are globally more sensitive to chromatic nuances because of historical and social factors. For this reason, this aspect could have an impact on our blue hues' discriminations, on perceptual differences and / or in color naming, too. Deeper investigations are required to better understand whether gender can really determine changes in our results or whether there just would be statistically insignificant variations in our data set.

From a methodological point of view, one aspect that could be improved is the indirect investigation of the light blue color in the Stroop task. In fact, we did not incorporate the Italian color word *azzurro* in the Italian experiment since it would create a discrepancy with the French experiment, lacking the corresponding French word. Our priority has been to preserve the homogeneity and the equal correspondence between the two languages experiments, in order to avoid bias and to limit the possible impact of methodological differences on the outcomes. However, it would be necessary to find an alternative way to directly analyse the word *azzurro* as a color word stimulus, written both in dark blue and in light blue, in comparison to French.

Another limit of our study concerns the definition of focal colours. In fact, for the dark blue and the light blue colours we used the foci identified in previous studies, notably G. Paramei et al. 2016; G. V. Paramei, D'orsi, and Menegaz 2014; Paggetti and Menegaz 2013; Paggetti, Menegaz, and Paramei 2016, but we did not determine the focal colours of the two blue hues specific to our three groups of speakers, especially for the bilingual one. A color naming listing task before the planification of the experiment could be a prerequisite for the identification of our participants' specific blue foci, which would be then used in the corresponding experiments. Both color patches and images representing natural objects and artifacts could be used in this kind of experiment: in fact, color perception and, thus, color naming can depend on the nature of the images represented. A complete set of stimuli is required to obtain a global specific result about the foci chromatic coordinates.

These factors are strictly linked to future studies that could be conducted from the present project, which represents the starting point of several possible additional investigations and new experimental works.

5.2 Future perspectives

Starting from the results we obtained in the present research, various future directions can be discovered, especially the extension of our study to other types of speakers, the addition of new perceptual experiments integrating the methodological protocol, as well as the neurophysiological analysis of subjects' reactions.

Firstly, it would be interesting to replicate our study with the complementary group of bilinguals, notably Italian-French proficient bilinguals living in Italy. In this case, we could investigate whether their second language categories (French) have an impact on color perception, as for the French-Italian bilinguals we tested. Since Italian is their dominant language and since French lacks the blue category distinction, Italian-French bilinguals are supposed to behave like Italian native monolinguals. However, they could also show similar performances as the French-Italian bilingual group: in this case, the bilingual mind would represent a distinct lexical-perceptual system with its proper functioning, processing visual perception independently to the monolingual mind.

Another group of speakers that could be analysed is a children group: age-based investigations of color perception have already opposed childhood to adulthood performances showing differences in color naming and, thus, in perceptual judgment. Children can, in fact, be more sensitive to color hues variations, which are linked to their color experience, that is sometimes finer compared to adults, even though more limited in the amount and the nature of events. Testing children could contribute to understand the evolutionary stages of color perception as well as of the individual color lexicon constitution, depending on the mother tongue and its color categories.

Moreover, we aim to reproduce our study with a group of English monolingual speakers in order to compare our results with those obtained by Winawer and colleagues. Since their study lacks some methodological details, it would be suitable to test English speakers once again with our experimental protocol, comparing them to our control group of French monolinguals. We would, thus, expect congruent results between the two groups, even though our French speakers did not show any similarities with Winawer's English speakers in their performances.

English speakers would also add relevant information about color categorisation of a German language, in comparison to two typologically neighbouring Roman languages.

Furthermore, our experimental protocol could be more complete with additional perceptual experiments: an Oddball paradigm and a Visual Search Task would be suitable, as well as a Color Naming Experiment to verify the hypothesis of whether a shift of the focal color corresponding to the blue color category, identified by the word *bleu*, has occurred in French.

The Oddball paradigm, inspired by the model of Thierry et al. (2009), would test the pre-attentive phases of color perception, potentially influenced by the subjects' native language. Using dark and light blue stimuli as well as control dark and light green stimuli, would enable us to attest the existence of two BCTs in Italian distinguishing light and dark blue, visible in increased vMMN (visual Mismatch Negativity) activity for the two blues. In fact, Italian speakers and bilinguals are supposed to perceive deviant stimuli of the two blue hues as being different compared to light and dark green stimuli. vMMN effects for blue, which detects deviancy in pre-attentive changes of visual perception, would then not be greater in French participants.

The Visual Search Task inspired by the model of Gilbert et al. (2005), with the difference that the color boundary analysed would be between dark blue and light blue, is another perceptual task where the relationship between linguistic color categories and cognitive organization can be explored. In this task, targets and distractors can belong to the same color category or to different color categories: following previous studies, cross-category

targets are identified faster than within-category targets, but only in the right visual field. The dark-light blue category boundary, lexically structured and stable in Italian but not in French, would represent additional findings about the evidence that cross-linguistic lexical differences can influence color perception in early and late processing, evident in ERP responses across scalp electrodes to pre-attentive novelty of a stimulus (Roberson, Pak, and Hanley 2008). Regions in the left hemisphere of the brain, in fact, seem to process language information through a top-down mechanism which influences visual areas functioning in color perception.

These two experiments are directly connected to additional neurophysiological analyses that would be interesting to conduct to extend our knowledge about the impact of language on perception.

The Visual Search Task could, in fact, allow us to explore the Whorf effect of lateralisation, which assumes that the influence of language is lateralized in the left hemisphere of the brain, the dominant for language processing (Gilbert et al. 2007; Gilbert et al. 2005; Drivonikou et al. 2007; Regier and Kay 2009). Therefore, since the visual field projects contralaterally to the brain, perception should be impacted by linguistic categories primarily in the right visual field, and weaker in the left visual fields, due to cross-callosal transfer of visual information.

However, since some studies did not replicate this brain lateralized effect, like those of Witzel and Gegenfurtner (2011), additional explorations in this field of study are required.

On the other hand, the Oddball paradigm can bring further evidence of the category effects at the neural level: through electroencephalogram analysis (EEG), it would be possible to measure the brain electrical activity during the task, comparing the three groups of participants. ERP components (like P1, N1 and vMMN for early components, and P2, N2, P3, N3 for post-perceptual components) would be chosen in order to investigate cognitive loci of the categorical effect, as well as perceptual mechanisms influenced by cognitive functions (pre-attentive modulation, novelty effects, spatial attention, high-level color processing).

From a neurophysiological point of view, it would be interesting to analyse the most involved brain regions during the Stroop task comparing the results from the three groups of speakers, too. In fact, two principal brain areas are involved in the Stroop Task processing, notably the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) (Milham et al. 2003), whose activity increases in conflict resolution. More specifically, the ACC is mostly involved in attention and selection of the pertinent response, whereas the DLPFC supports various executive functions, like memory, required to accomplish the goal. As a consequence, we aim to examine the electrical activity of French and Italian monolinguals and French-Italian bilinguals performing a Color Word Stroop Task, which should activate the areas of color perception, but not the regions of word semantics. For the blue color stimuli, we should obtain discrepancies in the activity increase since for some speakers they would represent a conflict to be solved, whereas for others they do not (only a classic Stroop Effect would be detected).

The last experiments we aim to conduct are two Color Naming tasks where a set of color stimuli embracing various color categories, including the BLUE one, from dark to light hues, would be presented to French and Italian monolingual and bilingual speakers. In the first part, subjects should freely name the color patches on the screen using monolexemic words; in the second part of the experiment, they would be asked to indicate the color patch representing, for them, the best example of a specific color category.

These two experiments would provide us more recent information about the French and Italian lexicon for different color categories, through the synchronic analysis of a possible evolution of the categories' color foci. Our study would especially be focused on the blue category in order to empirically verify the hypothesis of a shift towards more lightness hues of the focal color associated with the French color word *bleu*. This would also be the opportunity to discover whether French-Italian bilingual speakers identify different color hues for the blue and the azzurro categories compared to French and Italian monolinguals.

Furthermore, future perspectives which could be explored involve the analysis of other colours perception phenomena.

First, it would be interesting to reproduce our study in the green region of the color spectrum, as a form of control test. The same experimental protocol could be adapted to the green hues varying in lightness, from light to dark green, and performed by the same groups of speakers. We would expect any different processing or variations in behavioural data in the three groups, since French and Italian do not have distinct lexical categories between the two greens. Results should, thus, not correspond to the results we obtained in the present work. Therefore, color lexicon would be supposed to have an impact on color discrimination, where early and late stages of the color visual processing can depend on distinctions specific to the subject's native language.

Moreover, color boundaries between green and blue are not always strictly shaped between languages, since green components are integrated in blue hues varying in lightness labeled with specific monolexemic or compound color words.

Other color naming aspects varying cross-culturally and expected to influence color perception, similar to the studies conducted by Isabel Forbes on French differences between *brun* and *marron* (Biggam 2011; Forbes 1979), could complete the present study, bringing a more global portrait of the mechanisms linking color perception processing and language categorisation. In fact, the color spectrum has not been studied in depth in all its components yet.

For this reason, important and more exhaustive research from diverse fields of study is required in order to draw more general conclusions about the relation between color vision, language and cognitive functions.

To summarize, in this second chapter of the fourth part of the manuscript we have discussed the limits and the future directions of the current study.

In the first part we explained the aspects that should be ameliorated both from a theoretical and a methodological point of view, like the refinement of the bilingual group or the counterbalanced number of men and women participating in the experiences to avoid gender bias. The importance of the identification of the blue color foci specific to

our subjects, as well as the integration of the color word *azzurro* as a stimulus directly analyzable in the Stroop Task, have been highlighted, too.

In the second section, we discussed the future perspectives of the present project: additional speakers' groups, neurophysiological analysis, as well as further color perception phenomena are worth to be explored.

However, future research is required to clarify the mechanisms underlying the effect of cross-linguistic differences in color perception in the blue region, in conjunction with new color naming studies of additional areas of the color spectrum.

Conclusions

The external world is constantly shaped and partitioned in categories by the human mind (Siuda-Krzywicka et al. 2019; Kay and Kempton 1984; Bird et al. 2014; Brouwer and Heeger 2013; Thierry et al. 2009; Ozgen and Davies 2002). Categorization is a universal competence helping the definition and the identification of components in reality; categorical perception seems to have a facilitatory effect in the discrimination of elements belonging to the same category as compared to those of distinct categories (Harnad 1987).

The main purpose of this PhD thesis has been to bring additional evidence to the existence of a twelfth Basic Color Term in Italian, namely *azzurro*, covering the light blue hues of the blue color spectrum, in a comparative approach with French, lacking this distinction. Moreover, we aimed to demonstrate that lexical categorisations can influence perception, especially color perception, as it has been attested by various studies showing cross-linguistic differences in chromatic perception. Research on color naming and color perception (Roberson, Pak, and Hanley 2008; Regier, Kay, and Cook 2005; Wierzbicka 2008; Roberson and Davidoff 2000; Davies and Franklin 2002; Paggetti, Bartoli, and Menegaz 2011; Paggetti and Menegaz 2013; Athanasopoulos 2009; Thierry et al. 2009) has, in fact, attested that the blue area of the chromatic spectrum can be considered an exception due to its partitioning on the lightness dimension in some languages.

The whole project is part of the theoretical debate between universalists (Kay and Regier 2003; Regier, Kay, and Cook 2005) and relativists (Sapir 1929; Whorf 1956; Brown and Lenneberg 1954; Lucy 1992; Gumperz and Levinson 1996), still unsolved, supporting the weak versions of the two theories, through a structured experimental method. For this reason, the role of language on perception is investigated during extra-linguistic tasks, especially fully perceptual tasks.

We performed two main experimental tasks, a Color Word Stroop Task and a Speeded Color Discrimination Task, with three kinds of speakers: French native monolinguals, Italian native monolinguals and French-Italian highly proficient bilinguals. This third group is directly linked to one of our objectives: the study of color vision treatment in the bilingual mind. The existence of a bilingual advantage is another central point in cognitive linguistics which analyzes the impact of the constant simultaneous activation of two

linguistic systems in bilinguals (Grosjean 1989; Houwer 2009; De Groot 2011; Slobin 1996; Bialystok 2017; Kroll and Bialystok 2013; Green and Abutalebi 2013). Therefore, we examined the lexical and cognitive evolutionary phases of a second language mastery, through different mechanisms of adaptation and interiorization of the new conceptual system.

This research also added information about the construction and the discrepancies between two typologically similar languages, in a field of study still unexplored, where distinct aspects of cognition constantly interact.

The present PhD manuscript has been organized in the following way: after a brief introduction, the first part has been dedicated to the theoretical background, where in one chapter color vision and perception have been considered as a combination of physical and psychological processes, and in another chapter, we discussed about bilingualism, mentioning the different variables defining it and the various contrasting positions about this phenomenon. Then, we presented our study in detail explaining the methods used: the two main experiments, as well as the complementary tests, have been presented in detail, from the design to the hypotheses. The following part is composed of two chapters: one dedicated to the experimental results' presentation for each group, both in within-group comparisons and in between-groups comparisons, as well as to their interpretation and discussion, whereas the other one has been centered on the limits of the present study and on future directions.

The results we obtained from this research partially validate our original hypotheses and, at the same time, open new perspectives to additional exploring factors crucial to understanding the mechanisms underlying language and color perception. The main contributions of our study to the color vision field of study, to the blue semantics question, as well as to the bilingual controversy are the following ones:

1. The Italian color word *azzurro* seems to have all the characteristics to be considered a Basic Color Term, following the definition of Berlin and Kay. In fact, results from our experiments have shown chromatic salience as well as a high degree of saturation leading to global naming consensus for which speakers identified it as a different color category composing the color spectrum. Empirical

data from the two experiments have, in fact, globally attested that there exist salient differences between the Italian lexicon, composed by two BCTs for blue (*blu* and *azzurro*), and the French color lexicon, where all the blue hues are covered by the same color word *bleu*. These discrepancies are reflected in extra-linguistic tasks' performances supporting the hypothesis that language categories can exert an influence on perception, notably color perception, in combination with other cognitive factors participating to the discrimination visual process.

Therefore, different languages partitions divide the color spectrum in distinct ways, individually defining their proper color boundaries, which can change in time. Although the blue color is actually considered the most evident example of these color boundaries variations, other color hues need to be deeply analysed to obtain additional global information about the language-perception interconnection.

2. Since semantic categorisations have an impact on perceptual processes, what does it happen when one individual masters two different types of categorisations? Our bilingual group, composed by French-Italian proficient speakers, has shown contrastive results. In fact, for the Color Word Stroop Task we recorded the same behavioural performances as for the Italian monolinguals, demonstrating that they equally process the stimuli in the two languages, without any distinction. They have, thus, adopted the conceptual system of their L2 for each kind of categorisation: this means that the Italian lexical distinction for the two blue hues is strong enough to become the dominant one. Our hypothesis was confirmed.

Moreover, the Stroop effect that we globally obtained for all the participants is a relevant result about some cognitive functions, like automaticity, selective attention and inhibition processing, involved in visual perception in speakers of languages labelling color categories in different ways.

In contrast, results for the Speeded Color Discrimination Task did not reflect our hypothesis. In this case, the bilingual group did not show the same results as the corresponding Italian monolingual group: despite some common behavioural tendencies attested by statistical data, their reactions to the blue chromatic patches in different interference conditions produced a specific scenario. Therefore, proficient bilinguals probably do not always completely behave like monolingual speakers, being rather individuals with specific exclusive characteristics which cannot be compared to those of monolinguals. In fact, their concurrent concomitant double linguistic-conceptual systems constantly act in the bilingual mind, leading him/her to make decisions about the system to be used, which is not always the dominant one, to solve a task.

3. The online role of language during an objective perceptual task, as well as the emergence of a Category Advantage for distinct color boundaries, as attested by the results of Winawer and his colleagues' study (Winawer et al. 2007), has not been detected by the analysis of our experimental data.

In fact, we did not observe any advantage of category in the Italian group, corresponding to the Russian group of the authors, nor in the French-Italian bilingual speakers, supposed to perform like the Italian monolinguals. On the contrary, we found a Category Advantage in the French group, which we did not expect. However, the French CA was not disrupted by verbal interference stimuli, which means that the three experimental blocks are processed in the same way since lexical distinctions are absent in French. At the same time, the Italian monolingual group and the French-Italian bilingual speakers have shown specific behaviors which neither matched with our hypotheses nor they share relevant results. Each of them has, in fact, specific characteristics which can be explained by different linguistic and cognitive group-specific features.

As we explained in chapter 4, the discrepancies between our results and those of Winawer's experiments are probably caused by some differences in the groups' constitution as well as in methodological procedures (e.g., the lightness of the

background). It would be worthwhile to reproduce our study with English and Russian speakers, like Winawer's participants, in order to verify, or not, the effect obtained by the authors. Furthermore, they did not take into consideration the assumption that language, and thus linguistic categorisations, is not the only process to be directly involved in chromatic perception: several different cognitive and visual functions play a central role in color discrimination, and they cannot be left aside.

Despite the restrictions we have explained, we hope that our results could have brought a pertinent contribution to different domains of research, from color vision to cognitive linguistics, in the monolingual and multilingual mind. We are aware that some greatly debated questions, like the impact of language on cognition or the bilingual cognitive advantage, are still unsolved, but our results can support future additional studies shedding lighter on these scientific questions.

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Annexes

Additional material about the Experimental Design

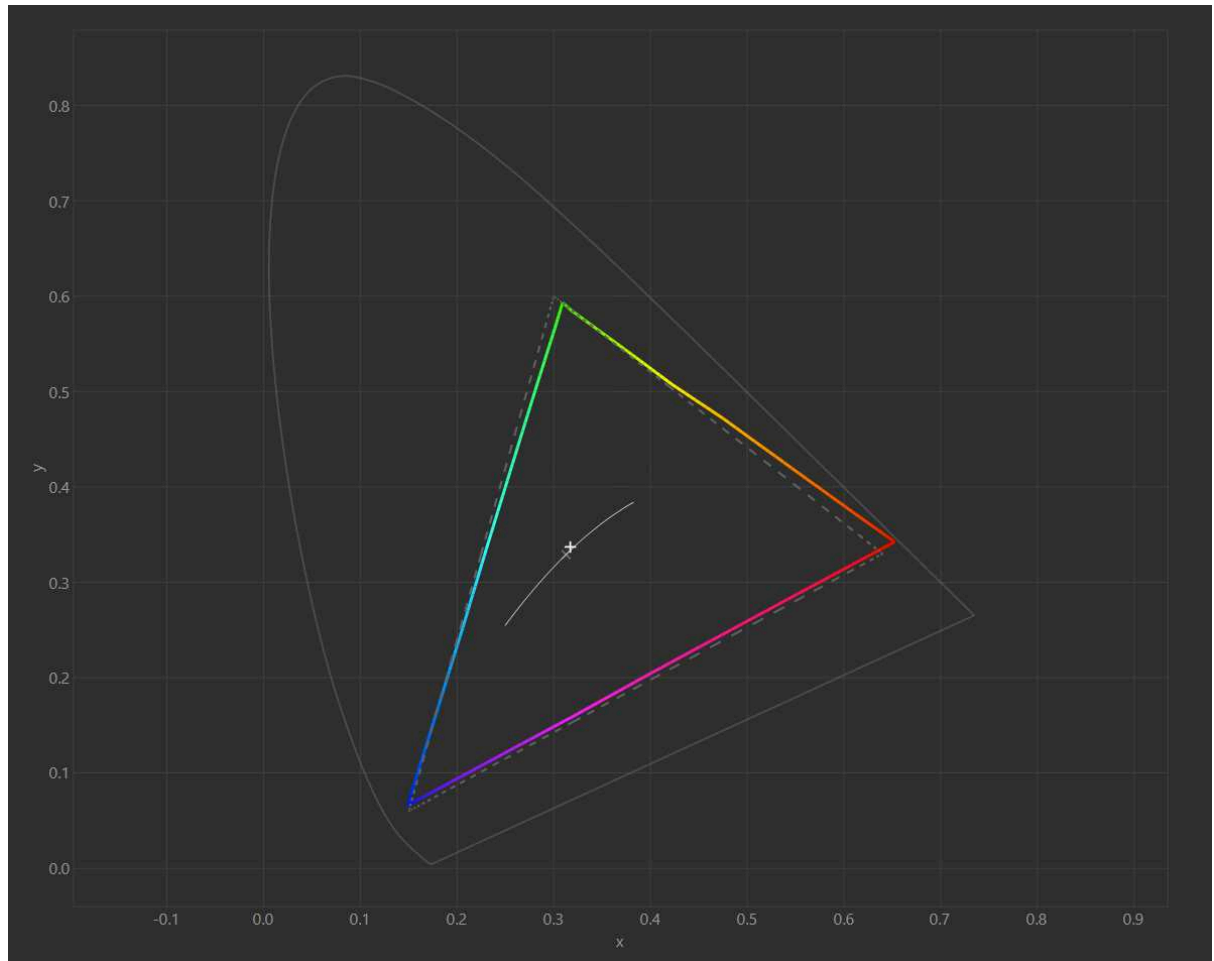


Figure 68: Experimental monitors' chromatic calibration details.

Color gamut of the calibrated monitors in CIE xy Color Space with white point and daily light color temperature curve. The rendering intent is absolute colorimetric, and the comparison profile is sRGB IEC61966-2.1 (equivalent to the www.srgb.com 1998 profile).

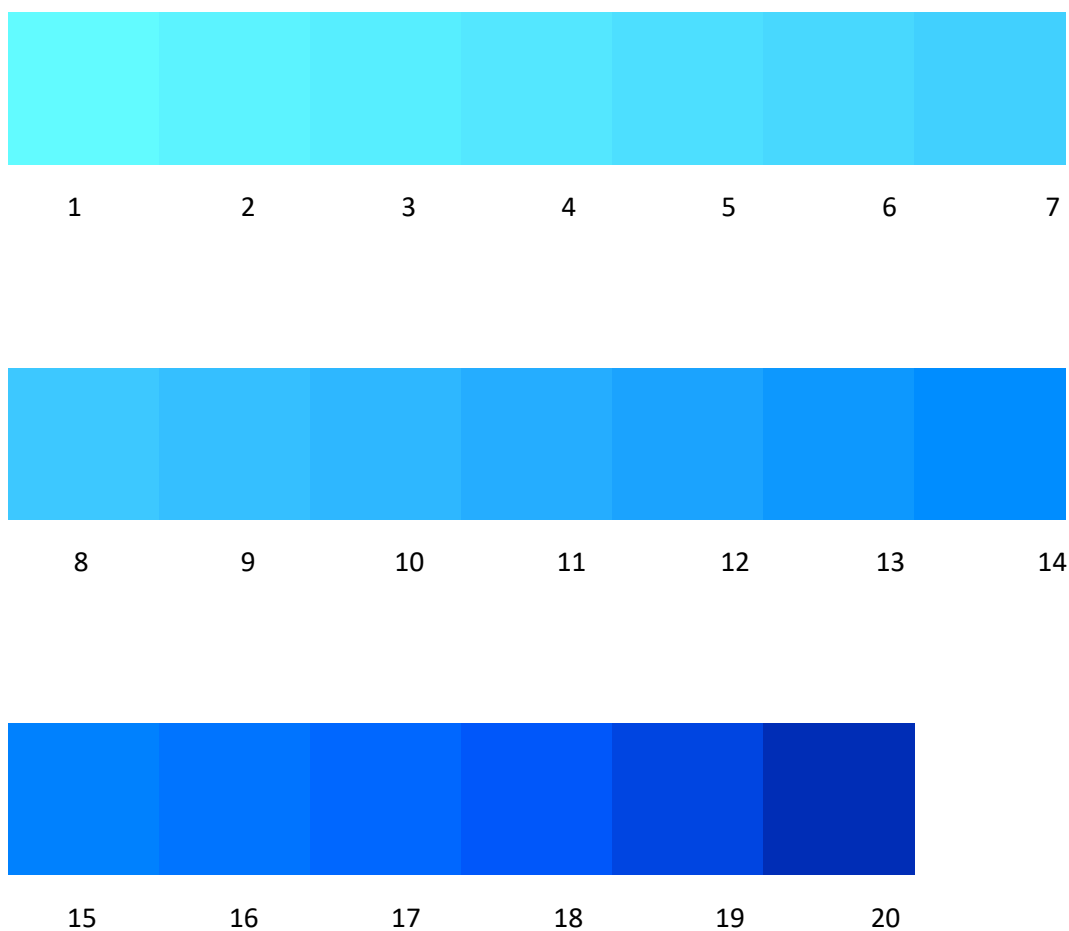


Figure 69: Color patches of the blue spectrum used in Experiment 2 (Speeded Color Discrimination Task), from *azzurro* to *blu*. Numbers (1 - 20) correspond to the patch's number used to discriminate color boundaries.

Additional information about participants' characteristics

	FRENCH	ITALIAN	BILINGUES
Country of birth			
France	80%		50%
Italy		100%	45%
Other	20%		5%
Travel abroad for more than 3 months			
%	60.67%	52.17%	63.64% (except Italy and France)
Main countries of traveling	Spain, Canada, Algeria, United Kingdom, Germany, Holland, Egypt	France, Spain, United Kingdom, Germany, Poland	United Kingdom, Philippines, Ireland, United States of America
Global Mean Time (in months)	9.92	10.25	17.72
Evaluation of the personal ability in learning a foreign language			
Really bad	4.17%	8.70%	0%
Mediocre	16.67%	8.70%	0%
Moderate	29.17%	21.74%	5.00%
Neutral	4.17%	13.04%	15.00%

Good	25.00%	21.74	45.00%
Very good	16.67%	21.74	25.00%
Excellent	4.17%	4.35%	10.00%
Mean Time spent in a foreign language depending on context (frequency of use)			
Mean frequency of use depending on people (hours per day/ Global MEAN)			
Family members	3.2	1.75	7.83
Friends	4.17	2.1	5.89
Colleagues/ Classmates	3.96	2.78	4.5
Mean frequency of use depending on activities (hours per day/ Global MEAN)			
Listening to radio	3.5	3.1	3.79
Watching television	1.78	1.23	2.4
Reading	1.70	1.35	2.15
Informal writing	0.5	0.75	1.35
Personal feeling of belonging to two or more cultures			
%	31.67%	13.04%	80%
Cross-linguistic words mixing when speaking			

%	60.83%	47.83%	75%
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Table 7: Supplementary information about life experiences and linguistic background of the three groups of participants, extracted from the questionnaire inspired by the model of Li, P., Zhang, F., Yu, A., & Zhao, X. (2020). *Language History Questionnaire (LHQ3): An enhanced tool for assessing multilingual experience*. *Bilingualism: Language and Cognition*, 23(5), 938-944, that they completed.

	FRENCH	ITALIAN	OTHER LANGUAGES
	MEAN (SD)	MEAN (SD)	MEAN (SD)
Age of acquisition	3,047 (5,945)	4,523 (6,85)	
Age of feeling comfortable in that language	4,57 (7,446)	6,476 (7,88)	
Number of years of school classes in that language	15 (5,431)	10,57 (6,786)	
Number of years spent in a country where that language is spoken	13,285 (7,403)	9,476 (8,09)	
Number of years spent in a working context where that language is spoken	7,714	2,047	
Frequency of usage of that language with friends in a week (in %)	75,71 %	39,52 %	16,66%
Frequency of usage of that language with family members in a week (in %)	63,33%	50,95%	1,43%
Frequency of usage of that language at school/ work in a week (in %)	83,33%	17,62%	20%
Frequency of usage of that language for mathematical operations and counting in a week (in %)	74,28%	45,24%	4,76%

Table 8: Supplementary information about French and Italian linguistic habits and use of the bilingual participants taken from the questionnaire inspired by the model of *Birdsong, D., Gertken, L.M., & Amengual, M. (2012). Bilingual Language Profile: An Easy-to-Use Instrument to Assess Bilingualism. COERLL, University of Texas at Austin.*

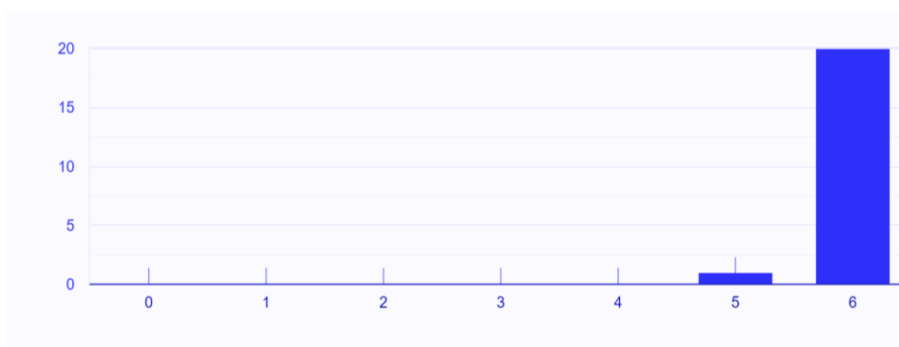
a. Personal evaluation of bilingual participants' linguistic competences

In the following section we present the individual personal evaluation of the four basic linguistic competences in French and Italian made by bilingual speakers: oral production, oral comprehension, written comprehension and written production.

We report the survey's questions translated into English, as well as the global statistical score corresponding to the participants' answers.

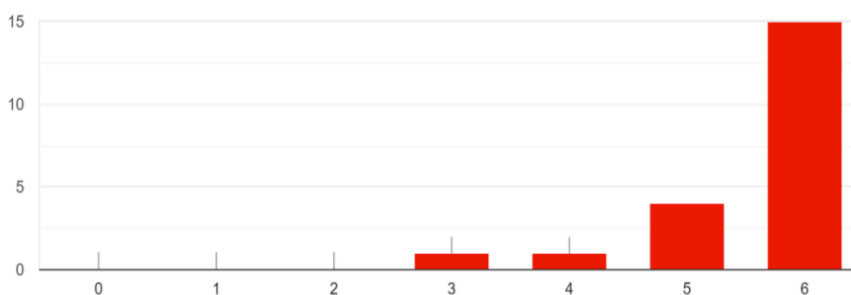
The rating scale goes from 0 (not at all) to 6 (very well).

Question 1: Do you speak French very well?



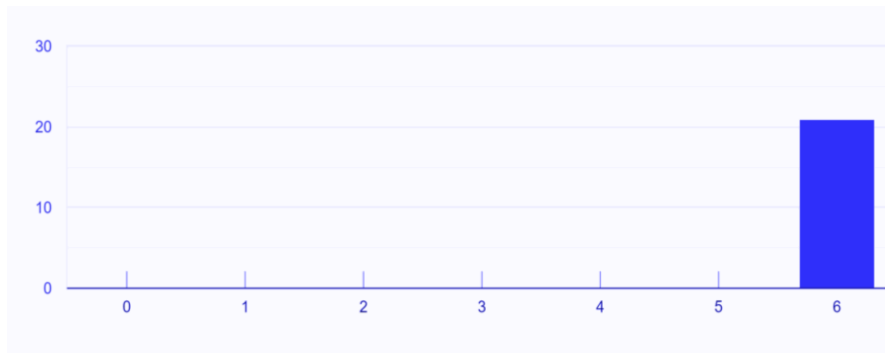
Answers' score: 5 = 1 (4,8%), 6 = 20 (95,2%)

Question 2: Do you speak Italian very well?



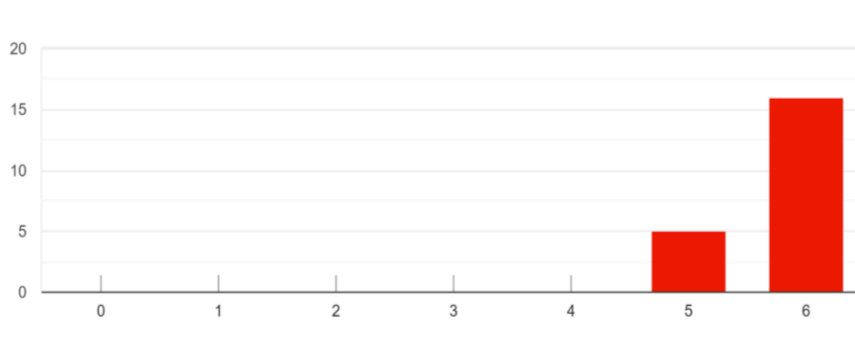
Answers' score: 3 = 1 (4,8%), 4 = 1 (4,8%), 5 = 4 (19%), 6 = 15 (71,4%)

Question 3: Do you understand French very well?



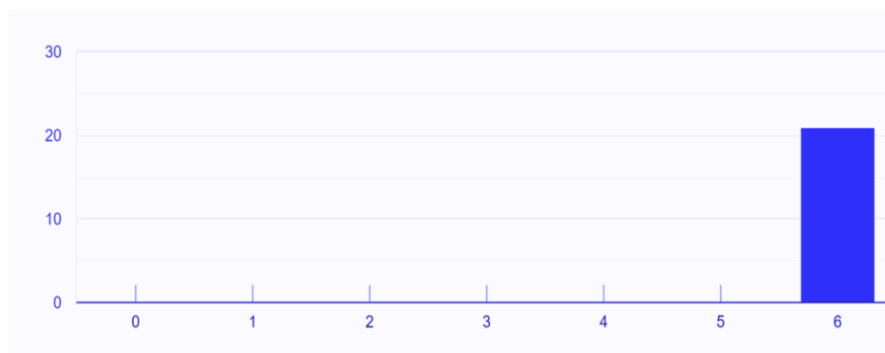
Answers' score: 6 = 21 (100%)

Question 4: Do you understand Italian very well?



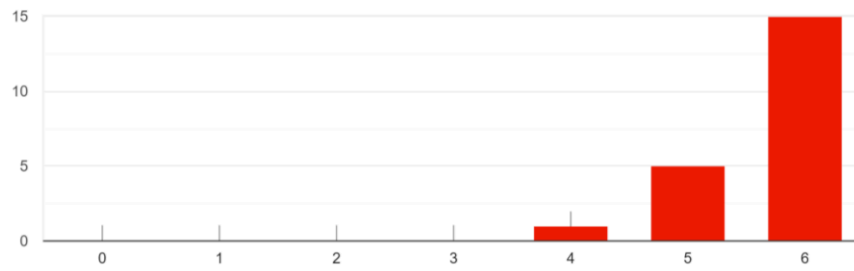
Answers' score: 5 = 5 (23,8%), 6 = 16 (76,2%)

Question 5: Do you read well in French?



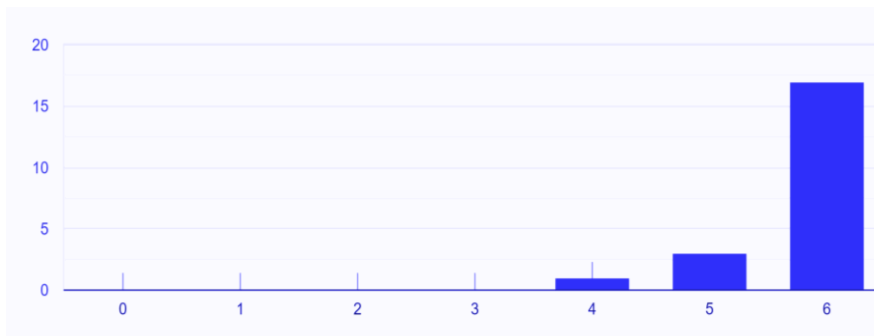
Answers' score: 6= 21 (100%)

Question 6: Do you read well in Italian?



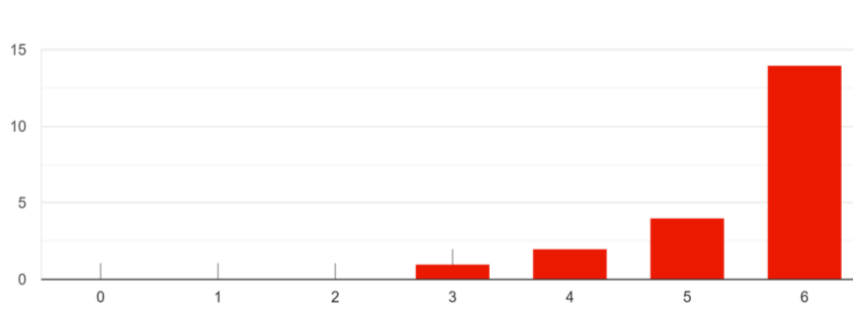
Answers' score: 4= 1 (4,8%), 5= 5 (23,8%), 6= 15 (71,4%)

Question 7: Do you write well in French?



Answers' score: 4= 1 (4,8%), 5= 3 (14,3%), 6= 17 (81%)

Question 8: Do you write well in Italian?



Answers' score: 3= 1 (4,8%), 4= 2 (9,5%), 5= 4 (19%), 6= 14 (66,7%)

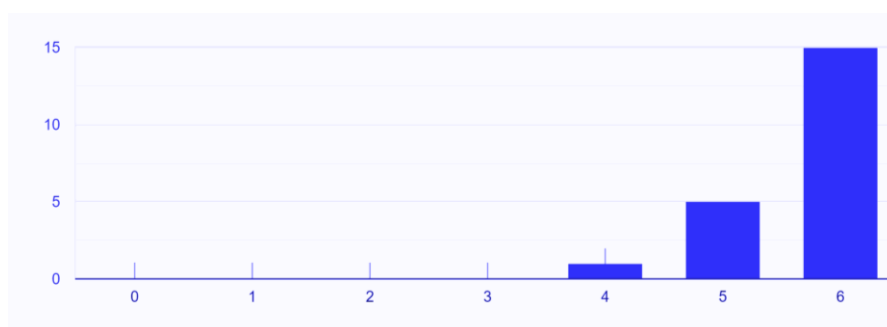
b. Personal evaluation of bilingual participants' attitudes and behaviors

In the next section we present the individual personal evaluation of the linguistic personal attitudes and behaviors in French and Italian made by bilingual speakers.

We report the survey's questions translated into English, as well as the global statistical score corresponding to the participants' answers.

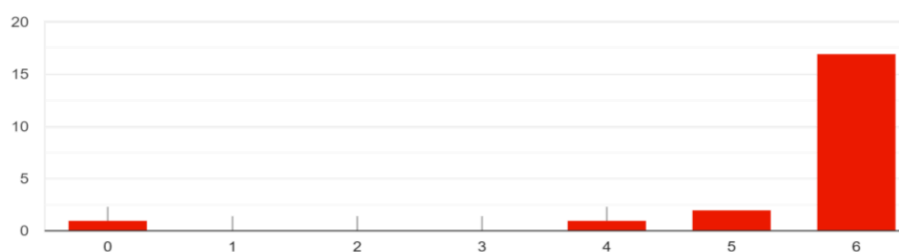
The rating scale goes from 0 (I completely disagree) to 6 (I fully agree).

Question 9: I feel myself when I speak French



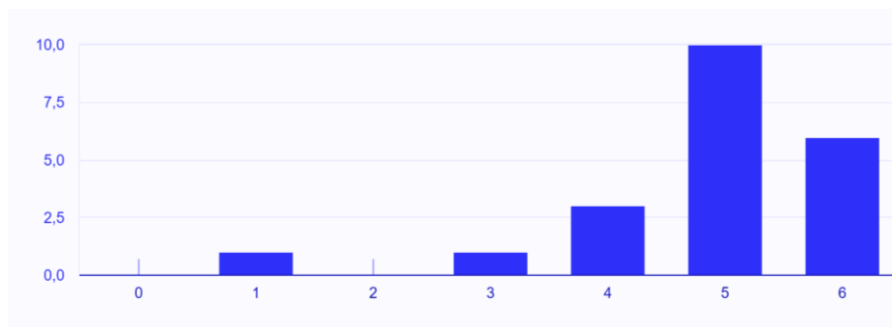
Answers' score: 4= 1 (4,8%), 5= 5 (23,8%), 6= 15 (71,4%)

Question 10: I feel myself when I speak Italian



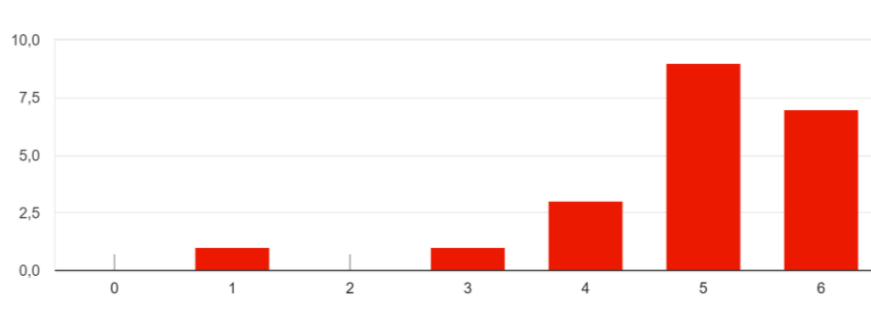
Answers' score: 0= 1 (4,8%), 4= 1 (4,8%), 5= 2 (9,5%), 6= 17 (81%)

Question 11: I identify myself with a French culture



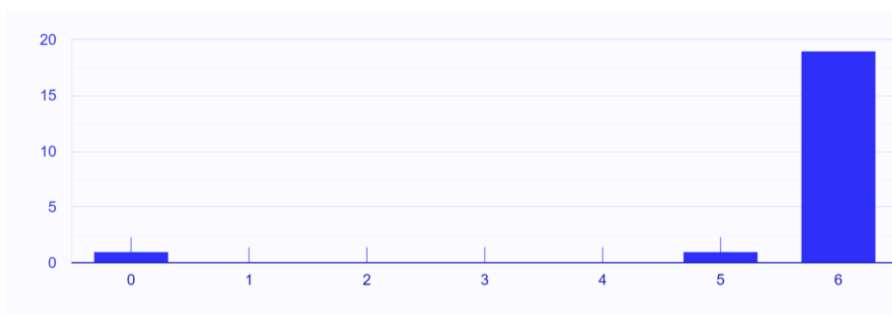
Answers' score: 1= 1 (4,8%), 3= 1 (4,8%), 4= 3 (14,3%), 5= 10 (47,6%), 6= 6 (28,6%)

Question 12: I identify myself with an Italian culture



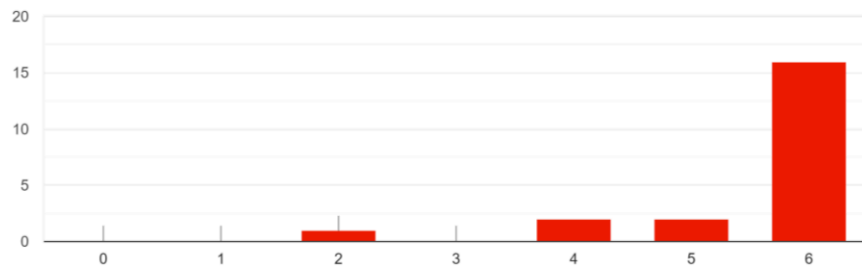
Answers' score: 1= 1 (4,8%), 3= 1 (4,8%), 4= 3 (14,3%), 5= 9 (42,9%), 6= 7 (33,3%)

Question 13: For me it is important to use French like a native speaker



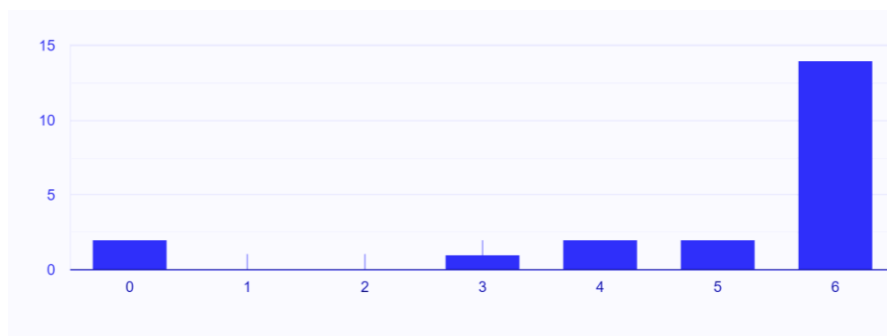
Answers' score: 0= 1 (4,8%), 5= 1 (4,8%), 6= 19 (90,5%)

Question 14: For me it is important to use Italian like a native speaker



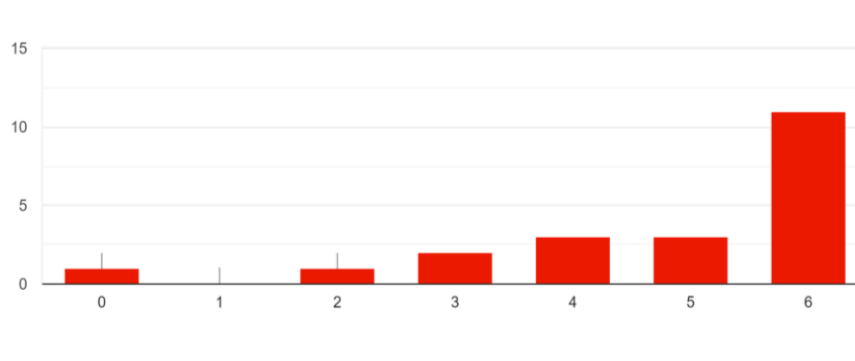
Answers' score: 2= 1 (4,8%), 4= 2 (9,5%), 5= 2 (9,5%), 6= 16 (76,2%)

Question 15: I would like that people believe that my mother tongue is French



Answers' score: 0= 2 (9,5%), 3= 1 (4,8%), 4= 2 (9,5%), 5= 2 (9,5%), 6= 14 (66,7%)

Question 16: I would like that people believe that my mother tongue is Italian



Answers' score: 0= 1 (4,8%), 2= 1 (4,8%), 3= 2 (9,5%), 4= 3 (14,3%), 5= 3 (14,3%), 6= 11 (52,4%)

Anonymized authentic bilinguals' statements

In the following table we report the declarations recorded on the online survey we submitted to our bilingual participants. They have been voluntarily written by participants who aimed to add relevant information about their linguistic background and multicultural experiences.

We have intentionally left all the grammatical, lexical and orthographic mistakes to preserve authenticity.

In order to allow universal understanding, at the end of the table, we included the English translation made by us.

French Authentic version

Participant ID	Authentic Recorded Declarations
2	L'italien est la première langue que j'ai commencé à parler quand j'étais enfant car j'ai fait l'asilo nido en Italie. Je suis arrivée en France à 5 ans (pour la grande section de la maternelle) et j'ai commencé à parler français à ce moment, même si en Italie ma mère me parlait déjà en français à la maison.
5	Mes deux langues maternelles sont l'italien et le français (mère italienne et père français) J'ai toujours été scolarisée dans le système français, en Italie jusqu'à mes 13 ans puis à Paris.
8	Je considère que j'ai deux langues maternelles: le Français et l'italien (même si ici j'ai indiqué le Français comme ma première langue étrangère). J'ai appris les deux depuis que je suis née et j'ai appris à écrire les deux langues en même temps aussi. J'ai grandi en Italie jusqu'à mes 18 ans en fréquentant une école française (de 3 à 13 ans). Ayant fréquenté un lycée 100% italien (de 13 à 18 ans), j'ai abandonné le Français écrit pendant quelques années et je le parlais moins souvent mais je ne l'ai bien évidemment pas oublié Une fois arrivée en France pour mes études universitaires (à 18 ans), j'ai assez vite repris une certaine naturalité dans le fait de parler et écrire en Français. Comme mes études ont été moitié en Anglais et moitié en Français, j'ai immédiatement pris l'habitude de compléter certaines phrases avec des mots anglais ou français selon l'expression que

	<p>j'avais oublié sur le moment. Avec les autres étudiants de mon cours nous avons tous pris cette habitude qui est restée jusqu'à aujourd'hui à l'oral et à l'écrit. Dernière précision, avec une amie proche (franco-italienne comme moi), nous faisons toujours un mix d'italien, Français et Anglais, à l'écrit et à l'oral. C'est par praticité/rapidité plus que par volonté, je ne m'en aperçois pas vraiment sur le moment.</p>
16	<p>Je vis dans une colocation avec mon amoureux (français) avec qui on parle presque toujours français avec des mélanges parfois d'anglais ; et avec une amie colombienne avec laquelle on parle presque toujours en français avec des mélanges parfois en espagnol. Etant italienne 'doc', avec ma famille on ne parle qu'italien : on communique par téléphone quelques fois par semaine + j'écoute des émissions d'infos en italien principalement, mais il m'arrive de les écouter en français et en anglais. Je lis aussi des articles en anglais, mais l'espagnol est la langue que malheureusement j'utilise avec moins de fréquence.</p>
20	<p>J'ai beaucoup parlé et échangé en anglais avec des collègues et des amis qui ne sont pas européens et qui ont une langue maternelle complexe. Je ne suis pas proche de la culture britannique mais j'apprécie plus l'anglais britannique que américain. L'italien : je l'ai appris et pratiqué réellement suite à un séjour en Erasmus où j'ai eu la chance d'étudier en italien mais surtout d'être corrigé constamment par des camarades qui sont devenus des amis uniquement en italien. Le problème c'est que par la suite ils ont appris le français donc je communique beaucoup plus même avec eux en anglais aujourd'hui.</p>
24	<p>J'ai continué d'entretenir des relations très proches en Italie, même après les 2 années et demi vécues dans ce pays</p>
26	<p>En famille, ma mère me parlait français et mon père italien pendant toute mon enfance. Depuis que j'habite en France et que je parle français tous les jours (notamment avec ma partenaire), j'ai plutôt tendance (plaisir) à parler italien même avec ma mère, au téléphone ou quand je vais la voir en Italie. Aujourd'hui je me sens presque autant français qu'italien, ou en tout cas ça m'énerve lorsque je me sens réduire à l'une ou l'autre identité (notamment, ici en France, quand je me sens réduit à mon italianité).</p>
32	<p>Mon apprentissage des langues anglaise et espagnole s'est fait à l'école, je n'ai jamais pratiqué l'anglais avec des "natives" et pourtant je l'ai largement employé dans des contextes de loisir et professionnels. De plus, je n'ai pratiqué l'espagnol que lors de</p>

	colocations à l'âge de 25 ans. En revanche, l'apprentissage du français a été en autodidacte, après la fin de mes études, lors de mon arrivée en France. Certaines réponses pourraient donc être non applicables
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English Translation

Participant ID	Translated Recorded declarations
2	Italian is the first language I started to speak when I was a child since I went to kindergarten in Italy. I arrived in France when I was 5 (for the last year of kindergarten) and I started speaking French at this moment of my life, even though my mother spoke to me in French even when we lived in Italy.
5	My two mother tongues are Italian and French (my mother is Italian and my father is French). I have always been enrolled in French school, both in Italy up until I was 13 and in Paris.
8	<p>I can consider that I have two mother tongues: French and Italian (even though here I said that French is my first foreign language). I learnt the two languages from my birth and I simultaneously learnt to write in them, too. I grew up in Italy until I was 18 attending French school (from 3 to 13). Since I studied in a 100% Italian high school (from 13 to 18) I left apart the written French during some years, speaking it less frequently, but I did not forget it obviously.</p> <p>Once I arrived in France for my university studies (at 18), I rapidly rediscovered a sort of naturalness in speaking and writing in French. Since half of my university courses were in English and the other half in French, I got into the habit of completing some phrases with French or English words depending on the expression I have forgotten. With the other students of my university courses we have this habit which has remained until nowadays in oral and written speaking. The last information, with one of my close friends (French-Italian like me), we always use a mix language between Italian, French and English, in written and oral speaking. This habit is due to practical reasons and rapidness rather than for willingness; I am not really aware of that at</p>

	the time.
16	I live with my boyfriend (French) with whom I speak almost always in French with some mixing English sometimes, and with a Colombian friend with whom we speak almost always in French with some mixing Spanish sometimes. Being a “Doc” Italian, with my family I speak only Italian: we communicate by phone a few times a week + I listen to some news programs mainly in Italian, but it is possible that I listen to them in French and English, too. I also read articles in English, but Spanish is the language that unfortunately I use with less frequency.
20	I have talked and communicated in English with some colleagues and some friends who are not European, having a complex mother tongue, a lot. I don’t feel close to British culture but I appreciate British English more than American English. About Italian, I actually learnt and used it after my Erasmus experience when I could study in Italian and I could constantly be corrected by some of my classmates who became my Italian friends. The problem is that they then have learnt French, so today I speak with them much more in English.
24	I continue to maintain some close relationships in Italy, even after 2 and a half years of living in this country.
26	In my family, my mother spoke to me in French and my father in Italian during my whole childhood. Since I live in France and I speak French every day (especially with my girlfriend), I have rather a tendency (or a pleasure) to speak Italian even with my mother, on the phone or when I visit her in Italy. Today I feel almost as much French than Italian; in any case, it annoys me when I am reduced to only one of the two identities, notably here, in France, when I am reduced to my Italian spirit.
32	My English and Spanish learning has taken place at school, I have never spoken English with some native people even though I widely used it in professional and leisure contexts. Moreover, I practiced Spanish only in my shared apartment, when I was 25. On the contrary, I learnt French as a self-taught, after the end of my studies, when I arrived in France. Some answers could, thus, not be applicable.

The Color Word Stroop Task

Supplementary tables about experimental data

In this section we report additional data about Reaction Times (in milliseconds) and Accuracy (in percentage) with Standard Deviation (SD) both for the Blue Color Word Effect and the Stroop Effect in within-group comparisons and between-group comparisons.

The Blue Color Word Effect

a. Within-group comparison: BILINGUAL SPEAKERS

Descriptives					
Language	Congruency	Mixing	Mean	SD	N
French	Congruent	No Mixte	95.916	7.319	21
		Mixte	95.142	9.303	21
	Incongruent	No Mixte	95.768	8.222	21
		Mixte	91.797	18.142	21
Italian	Congruent	No Mixte	98.413	3.984	21
		Mixte	96.031	7.275	21
	Incongruent	No Mixte	93.122	8.941	21
		Mixte	97.260	8.517	21

Table 9: Mean Accuracy and Standard Deviation (in percentage) for French and Italian congruent and incongruent stimuli, in mixed and no mixed experimental blocks, performed by bilinguals.

b. Between-group comparisons

FRENCH vs ITALIAN

REACTION TIME

Descriptives				
Congruency	Groupe	Mean	SD	N
Congruent	French	719.804	151.049	22
	Italian	694.599	115.050	22
Incongruent	French	685.794	110.747	22
	Italian	718.978	145.613	22

Table 10: French vs Italian RTs for congruent and incongruent stimuli

ACCURACY

Descriptives

Congruency	Groupe	Mean	SD	N
Congruent	French	99.495	2.369	22
	Italian	96.402	6.395	22
Incongruent	French	97.813	8.128	22
	Italian	97.917	4.531	22

Table 11: French vs Italian Accuracy for congruent and incongruent stimuli

FRENCH vs BILINGUALS IN FRENCH

REACTION TIME

Descriptives

Congruency	Groupe	Mean	SD	N
Congruent	Bil.French	784.467	149.351	21
	French	719.804	151.049	22
Incongruent	Bil.French	853.919	199.107	21
	French	685.794	110.747	22

Table 12: French vs Bilinguals in the French experiment RTs for congruent and incongruent stimuli

ACCURACY

Descriptives

Congruency	Groupe	Mean	SD	N
Congruent	Bil.French	95.916	7.319	21
	French	99.495	2.369	22
Incongruent	Bil.French	95.768	8.222	21
	French	97.813	8.128	22

Table 13: French vs Bilinguals in the French experiment Accuracy for congruent and incongruent stimuli

ITALIAN vs BILINGUALS IN ITALIAN

REACTION TIME

Descriptives

Congruency	Groupe	Mean	SD	N
Congruent	Bil.Italian	765.811	111.167	21
	Italian	694.599	115.050	22
Incongruent	Bil.Italian	810.856	150.771	21
	Italian	718.978	145.613	22

Table 14: Italian vs Bilinguals in the Italian experiment RTs for congruent and incongruent stimuli

ACCURACY

Descriptives

Congruency	Groupe	Mean	SD	N
Congruent	Bil.Italian	98.413	3.984	21
	Italian	96.402	6.395	22
Incongruent	Bil.Italian	93.122	8.941	21
	Italian	97.917	4.531	22

Table 15: Italian vs Bilinguals in the Italian experiment Accuracy for congruent and incongruent stimuli

The Stroop Effect

c. Within-group comparison: BILINGUAL SPEAKERS

Descriptives

Experimental Block	Condition	Mean	SD	N
French	Congruent	95.670	4.121	21
	Incongruent	92.666	5.949	21
	Neutral	96.209	3.537	21
Italian	Congruent	96.964	3.275	21
	Incongruent	94.174	5.621	21
	Neutral	97.179	4.248	21
Mixte	Congruent	88.882	20.779	21
	Incongruent	88.866	17.740	21
	Neutral	89.417	20.447	21

Table 16: Mean Accuracy and Standard Deviation (in percentage) for the three conditions in the three experiments (French, Italian and Mixte) performed by bilinguals.

d. Between-group comparisons

Reaction Times (in milliseconds) and accuracy (in percentage) with Standard Deviation (SD) for the Stroop Effect: Congruency (Congruent - Incongruent, plus Neutral) is detailed for between-groups comparisons.

FRENCH vs ITALIAN

REACTION TIME

Descriptives

Condition	Groupe	Mean	SD	N
Congruent	French	721.321	129.812	22
	Italian	726.989	153.316	22
Incongruent	French	818.792	169.026	22
	Italian	836.880	206.377	22
Neutral	French	746.662	161.580	22
	Italian	738.420	137.542	22

Table 17: French vs Italian RTs for congruent, incongruent and neutral stimuli in the Stroop Effect Analysis

ACCURACY

Descriptives

Condition	Groupe	Mean	SD	N
Congruent	French	95.751	10.503	22
	Italian	97.054	3.987	22
Incongruent	French	90.579	12.392	22
	Italian	94.866	6.388	22
Neutral	French	95.401	11.557	22
	Italian	96.633	4.067	22

Table 18: French vs Italian Accuracy for congruent, incongruent and neutral stimuli in the Stroop Effect analysis

FRENCH vs BILINGUALS IN FRENCH

REACTION TIME

Descriptives

Condition	Groupe	Mean	SD	N
Congruent	Bil.French	827.640	142.398	21
	French	721.321	129.812	22
Incongruent	Bil.French	981.687	217.250	21
	French	818.792	169.026	22
Neutral	Bil.French	875.072	145.102	21
	French	746.662	161.580	22

Table 19: French vs Bilinguals in the French experiment RTs for congruent, incongruent and neutral stimuli in the Stroop Effect analysis

ACCURACY

Descriptives

Condition	Groupe	Mean	SD	N
Congruent	Bil.French	95.670	4.121	21
	French	95.751	10.503	22
Incongruent	Bil.French	92.666	5.949	21
	French	90.579	12.392	22
Neutral	Bil.French	96.209	3.537	21
	French	95.401	11.557	22

Table 20: French vs Bilinguals in the French experiment Accuracy for congruent, incongruent and neutral stimuli in the Stroop Effect analysis.

ITALIAN vs BILINGUALS IN ITALIAN

REACTION TIME

Descriptives				
Condition	Groupe	Mean	SD	N
Congruent	Bil.Italian	820.489	128.429	21
	Italian	726.989	153.316	22
Incongruent	Bil.Italian	954.224	173.939	21
	Italian	836.880	206.377	22
Neutral	Bil.Italian	870.148	159.632	21
	Italian	738.420	137.542	22

Table 21: Italian vs Bilinguals in the Italian experiment RTs for congruent, incongruent and neutral stimuli in the Stroop Effect analysis.

ACCURACY

Descriptives				
Condition	Groupe	Mean	SD	N
Congruent	Bil.Italian	96.964	3.275	21
	Italian	97.054	3.987	22
Incongruent	Bil.Italian	94.174	5.621	21
	Italian	94.866	6.388	22
Neutral	Bil.Italian	97.179	4.248	21
	Italian	96.633	4.067	22

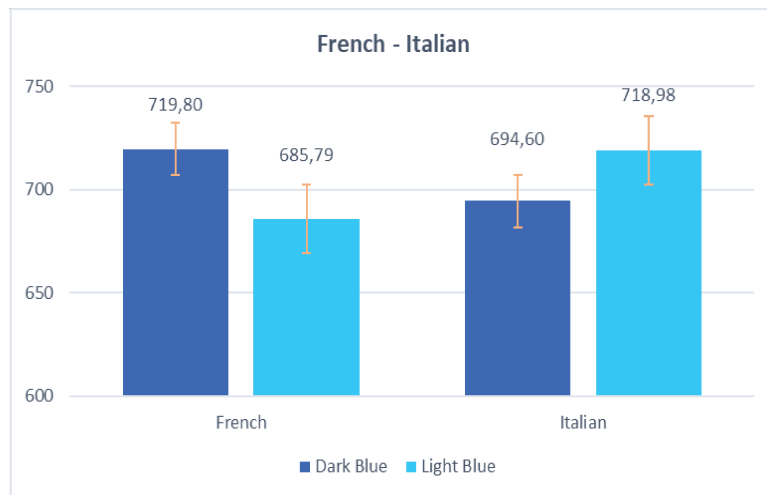
Table 22: Italian vs Bilinguals in the Italian experiment Accuracy for congruent, incongruent and neutral stimuli in the Stroop

Supplementary graphs about experiment's results

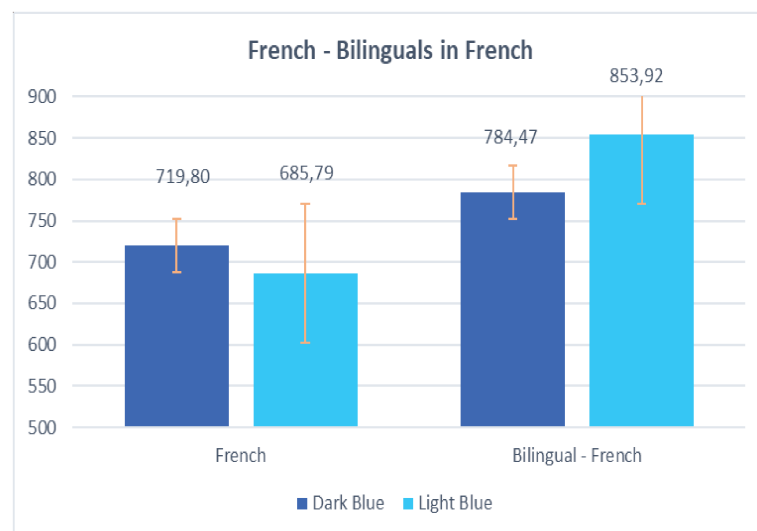
In this section we report additional graphs and charts representing some statistically significant results of the two main effects (the Blue Color Word Effect and the Stroop Effect) analysed for the Color Word Stroop Task.

The Blue Color Word Effect

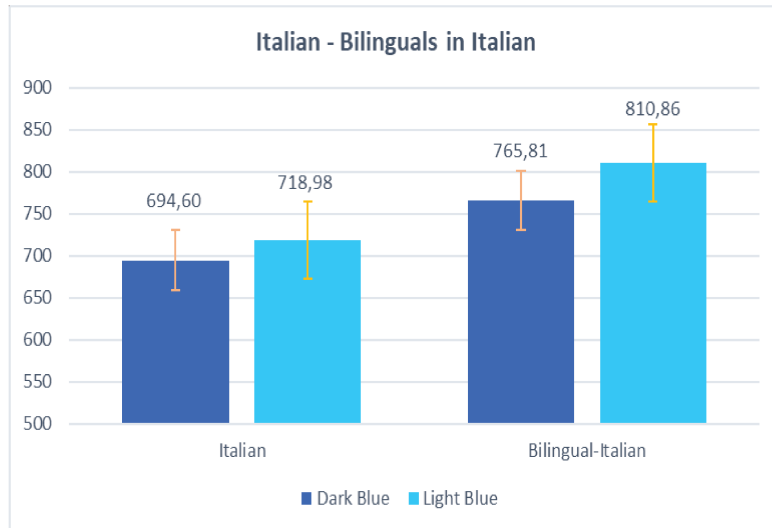
Mean Reaction Time (in milliseconds) of the Blue Color Word Effect groups' comparisons: values for stimuli written in dark blue and in light blue and Standard Error (SE) bars are displayed.



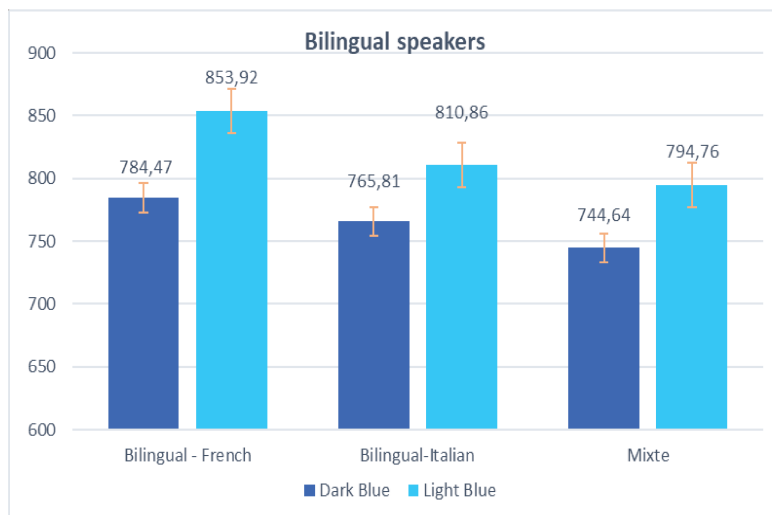
Graph 18: French vs Italian monolinguals.



Graph 19: French monolinguals vs bilinguals performing the French experiment.

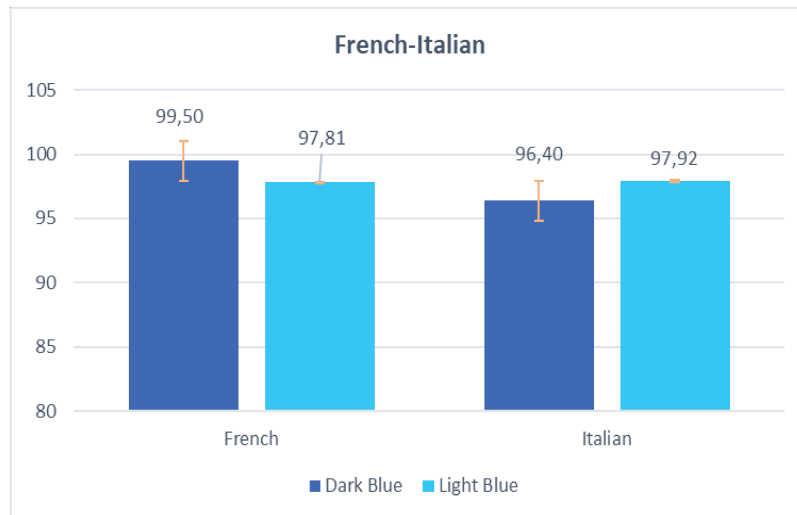


Graph 20: Italian monolinguals vs Bilinguals performing the Italian experiment.

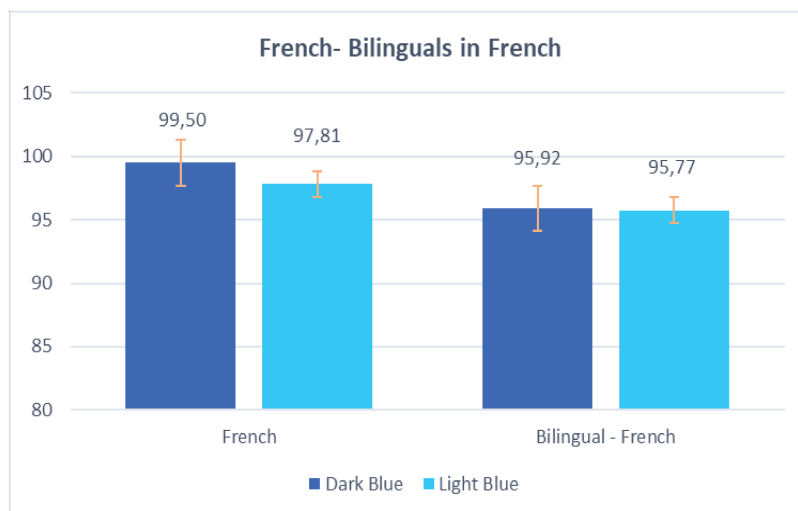


Graph 21: Bilingual speakers in the French, Italian and French-Italian mixed experiments.

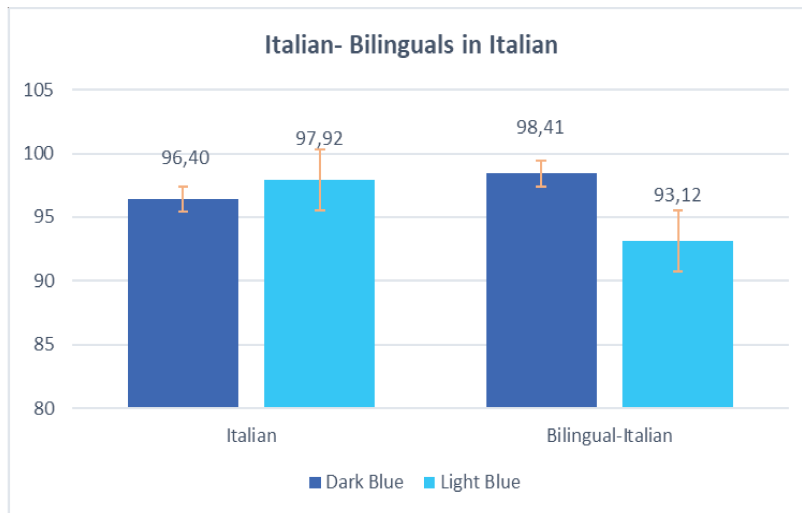
Mean Error Rate (in percentage) of the Blue Color Word Effect groups' comparisons: values for stimuli written in dark blue and in light blue and Standard Error (SE) bars are displayed.



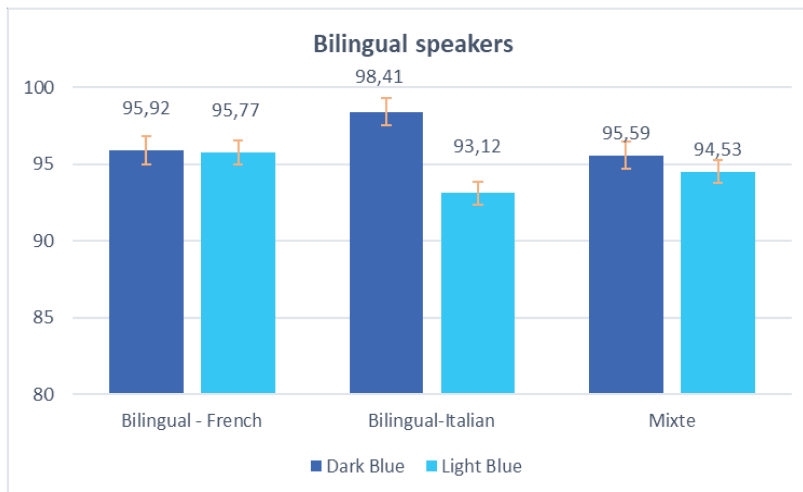
Graph 22: Accuracy for French vs Italian monolinguals.



Graph 23: Accuracy for French monolinguals vs Bilinguals performing the French experiment.



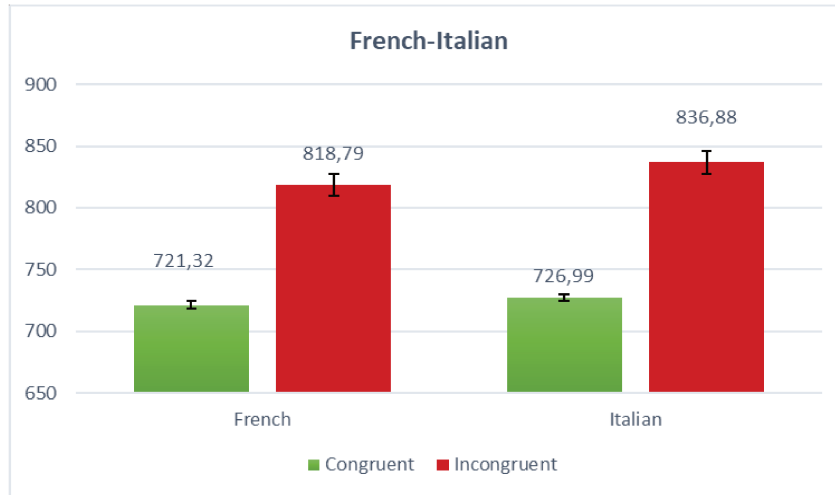
Graph 24: Accuracy for Italian monolinguals vs Bilinguals performing the Italian experiment.



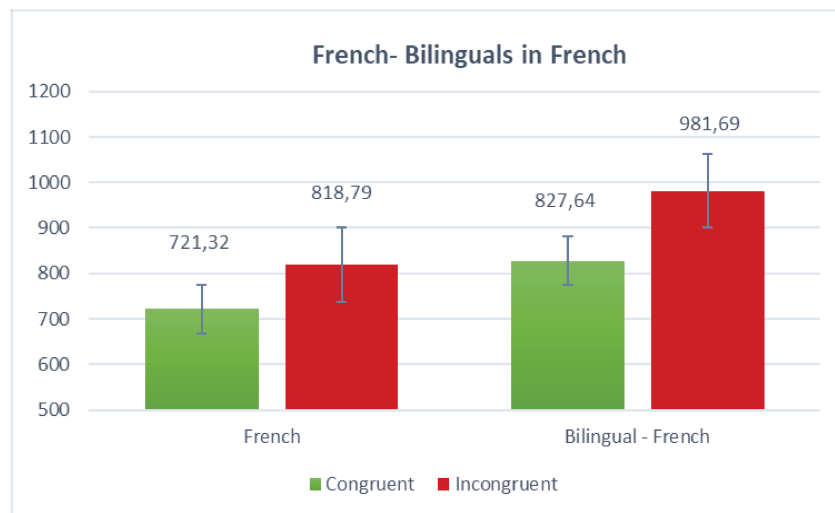
Graph 25: Accuracy for Bilingual speakers in the French, Italian and French-Italian mixed experiments.

The Stroop Effect

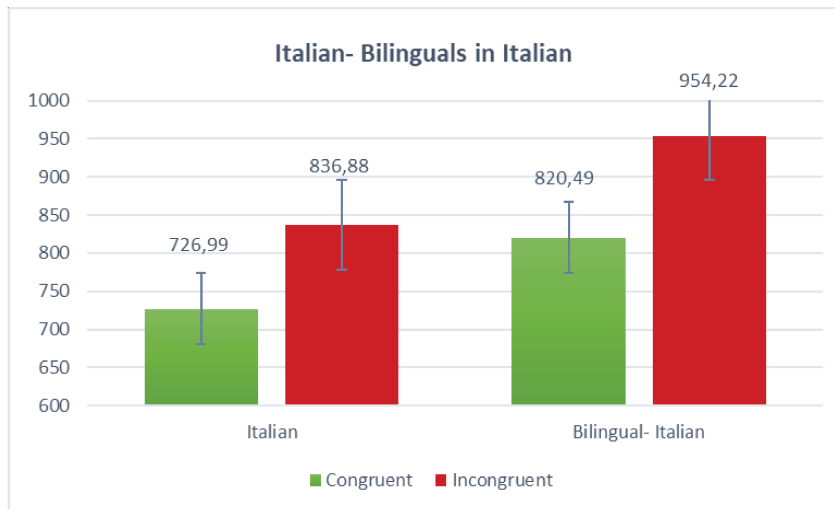
Mean Reaction Time (in milliseconds) of the Stroop Effect groups' comparisons: values for congruent and incongruent stimuli and Standard Error (SE) bars are displayed.



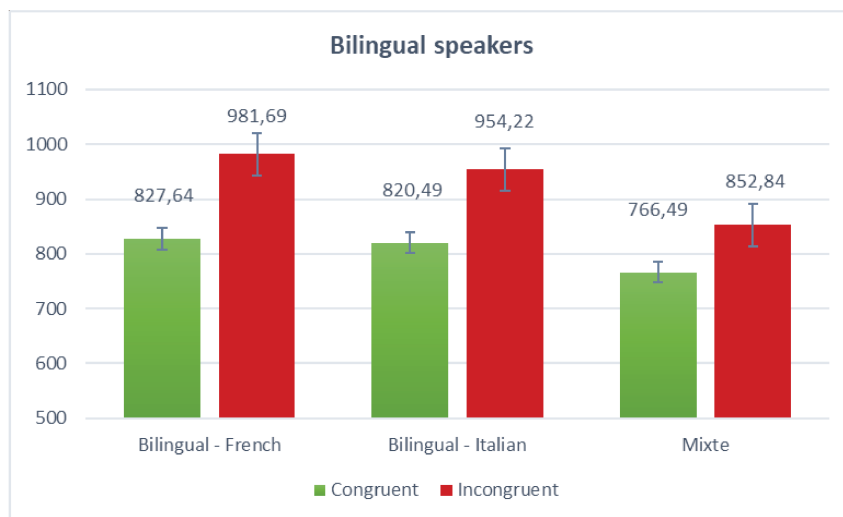
Graph 26: RTs for French vs Italian monolinguals



Graph 27: RTs for French speakers vs. Bilinguals performing the French experiment.

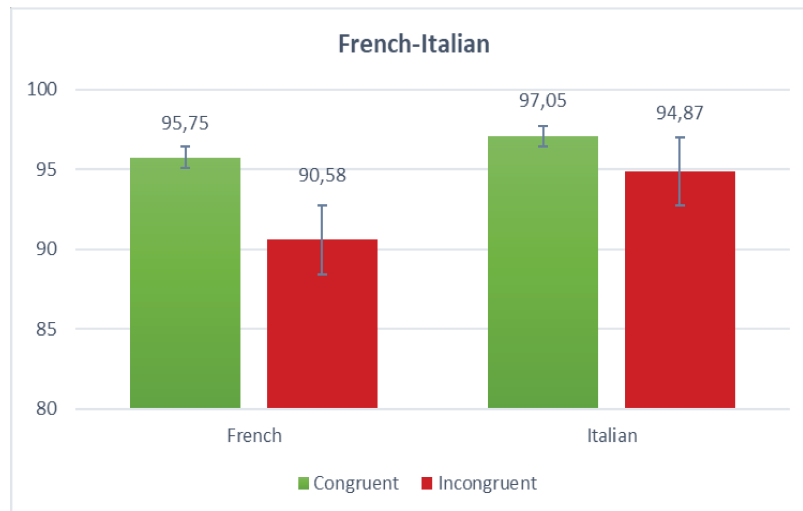


Graph 28: RTs for Italian monolinguals vs Bilinguals performing the Italian experiment

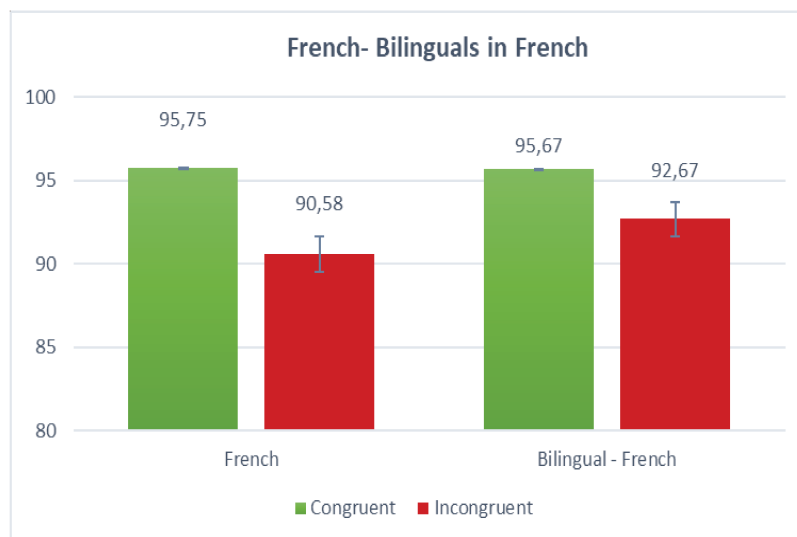


Graph 29: RTs for Bilingual speakers in the French, Italian and French-Italian mixed experiments

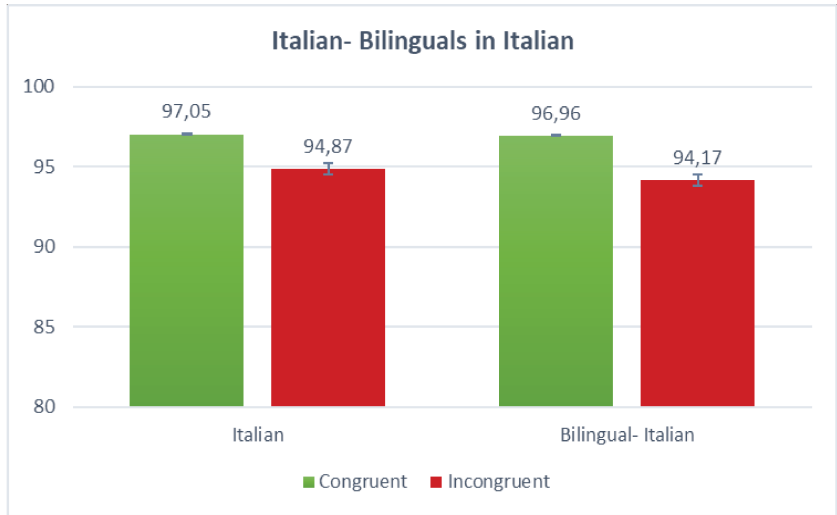
Mean Error Rate (in percentage) of the Stroop Effect groups' comparisons: values for congruent and incongruent stimuli and Standard Error (SE) bars are displayed.



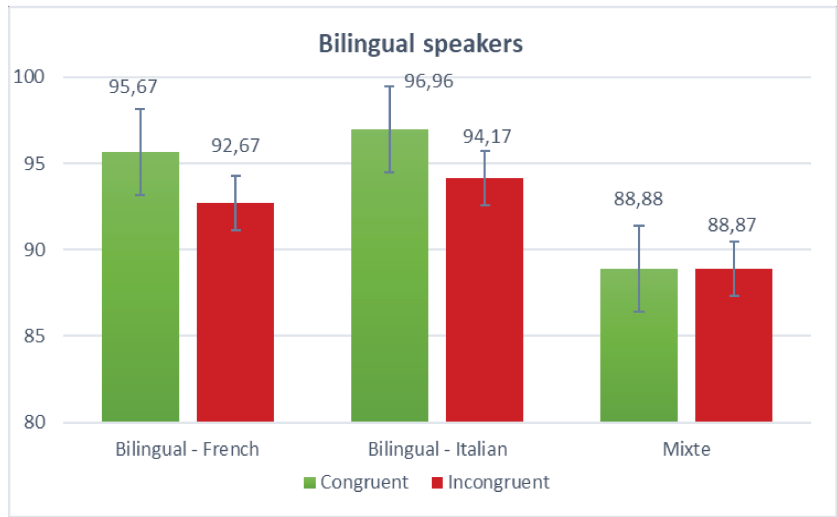
Graph 30: Accuracy for French vs Italian monolinguals.



Graph 31: Accuracy for French vs Bilinguals performing the French experiment.



Graph 32: Accuracy for Italian monolinguals vs Bilinguals performing the Italian experiment.



Graph 33: Accuracy for Bilingual speakers in the French, Italian and French-Italian mixed experiments.

The Speeded Color Discrimination Task

Supplementary tables about experimental data

In this section we report additional data about Reaction Times (in milliseconds) and Accuracy (in percentage) with Standard Deviation (SD) for the Category Advantage: the three-way interactions between Interference (No Interference Block, Verbal Interference Block and Spatial Interference Block), Category (Within-category and Cross-category) and Distance (Far-Near) of each group of participants are detailed.

FRENCH

REACTION TIME

Interference	Category	Distance	Mean	SD	N
No Int	Within	Far	777.640	176.492	22
		Near	897.055	208.766	22
	Cross	Far	763.625	185.683	22
		Near	842.442	233.796	22
Verbal Int	Within	Far	767.450	154.649	22
		Near	902.290	198.296	22
	Cross	Far	749.634	156.083	22
		Near	850.915	202.692	22
Spatial Int	Within	Far	760.314	137.981	22
		Near	868.748	169.651	22
	Cross	Far	729.992	149.190	22
		Near	842.730	180.245	22

Table 23: RTs for French speakers

ACCURACY

Interference	Category	Distance	Mean	SD	N
No Int	Within	Far	89.640	12.259	22
		Near	73.879	12.677	22
	Cross	Far	87.006	16.187	22
		Near	69.318	19.182	22
Verbal Int	Within	Far	91.821	8.839	22
		Near	73.516	12.616	22
	Cross	Far	87.452	15.510	22
		Near	71.780	18.895	22
Spatial Int	Within	Far	89.268	12.682	22
		Near	74.963	12.622	22
	Cross	Far	87.845	14.222	22
		Near	70.060	16.766	22

Table 24: ACC for French speakers

ITALIANS

REACTION TIME

Interference	Category	Distance	Mean	SD	N
No Int	Within	Far	754.788	144.830	21
		Near	956.307	167.603	21
	Cross	Far	766.348	150.497	21
		Near	926.841	176.135	21
Verbal Int	Within	Far	725.294	94.308	21
		Near	910.517	140.925	21
	Cross	Far	737.631	86.509	21
		Near	912.744	178.996	21
Spatial Int	Within	Far	743.764	108.441	21
		Near	939.211	160.335	21
	Cross	Far	746.140	97.934	21
		Near	903.707	160.522	21

Table 25: RTs for Italian speakers

ACCURACY

Interference	Category	Distance	Mean	SD	N
No Int	Whit	Far	98.297	2.278	22
		Near	86.742	4.564	22
	Cross	Far	97.176	5.688	22
		Near	85.714	16.496	22
Verbal Int	Whit	Far	98.196	2.256	22
		Near	88.737	5.201	22
	Cross	Far	98.580	3.303	22
		Near	85.922	14.499	22
Spatial Int	Whit	Far	98.479	1.851	22
		Near	87.722	6.456	22
	Cross	Far	98.095	5.285	22
		Near	85.795	13.527	22

Table 26: ACC for Italian speakers

FRENCH-ITALIAN BILINGUALS

REACTION TIME

Interference	Category	Distance	Mean	SD	N
No Int	Within	Far	862.779	161.227	20
		Near	1014.451	179.219	20
	Cross	Far	856.292	196.623	20
		Near	974.356	232.424	20
Verbal Int	Within	Far	833.306	124.857	20
		Near	1017.275	130.315	20
	Cross	Far	864.719	122.816	20
		Near	1049.881	155.956	20
Spatial Int	Within	Far	858.765	126.509	20
		Near	1031.135	137.977	20
	Cross	Far	850.535	133.101	20
		Near	1025.854	174.284	20

Table 27: RTs for Bilingual speakers

ACCURACY

Interference	Category	Distance	Mean	SD	N
No Int	Within	Far	90.080	9.428	20
		Near	73.133	11.161	20
	Cross	Far	88.750	11.217	20
		Near	69.875	16.292	20
Verbal Int	Within	Far	91.469	11.776	20
		Near	75.173	15.602	20
	Cross	Far	89.540	14.210	20
		Near	68.125	18.351	20
Spatial Int	Within	Far	93.557	8.502	20
		Near	75.402	13.105	20
	Cross	Far	89.688	15.076	20
		Near	68.125	20.064	20

Table 28: ACC for Bilingual speakers

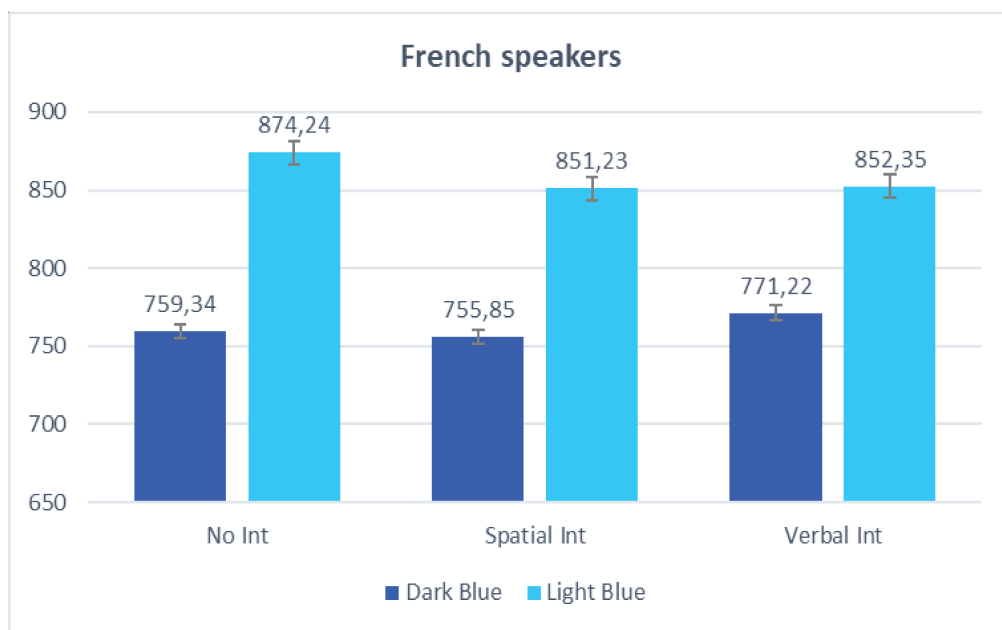
Supplementary graphs about experiment's results

In this section we report additional graphs and charts representing some statistically significant results of the two main effects (the Color Patch Effect and the Category Advantage) analysed for the Speeded Color Discrimination Task.

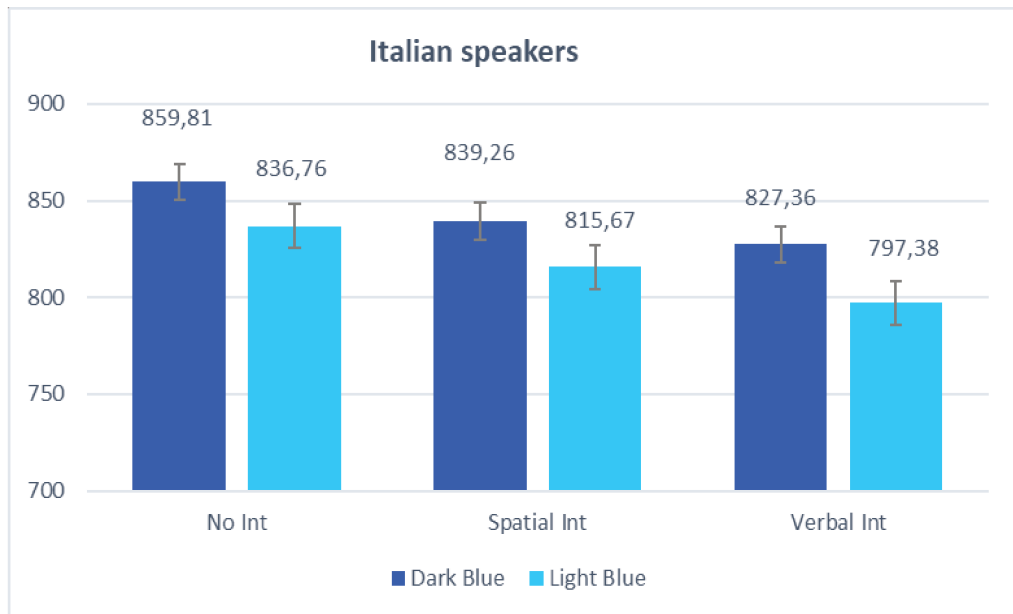
The Color Patch Effect Analysis

RTs and Accuracy for the Color Patch Effect

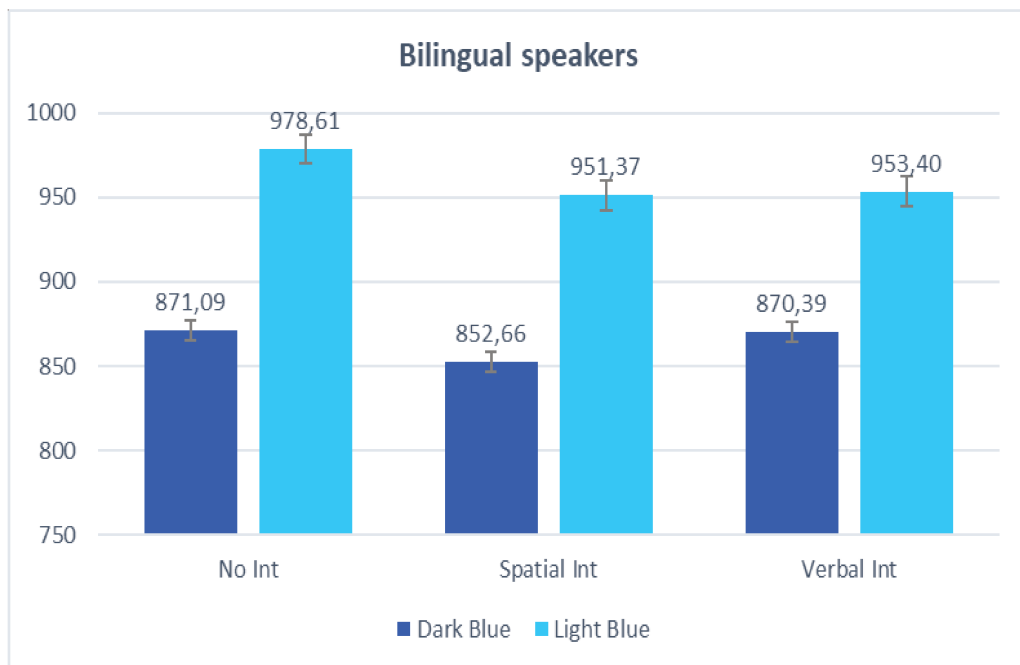
Mean Reaction Time (in milliseconds) of the Color Patch Effect with Standard Error (SE) bars. For each group of participants, the two-way interactions between the color patch category (dark blue or light blue) and the experimental condition (No Interference Block, Spatial Interference Block and Verbal Interference Block) are displayed.



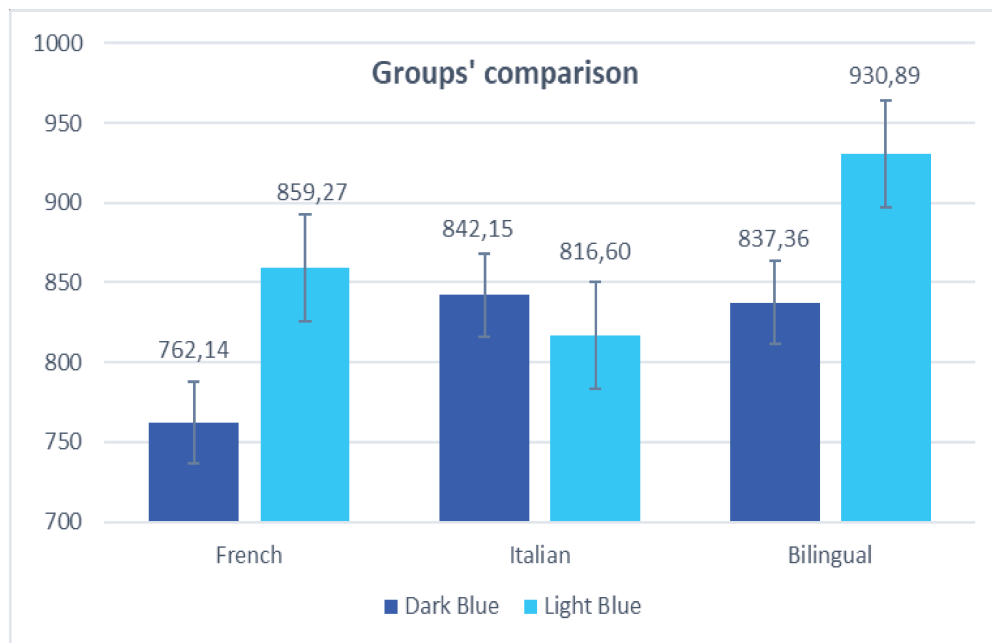
Graph 34: RTs for French monolinguals



Graph 35: RTs for Italian monolinguals

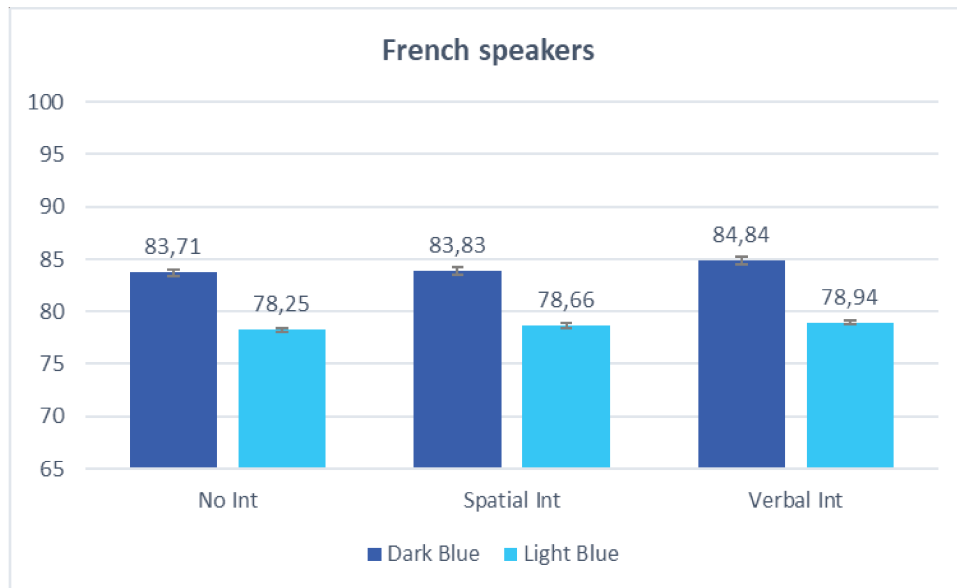


Graph 36: RTs for French-Italian Bilingual

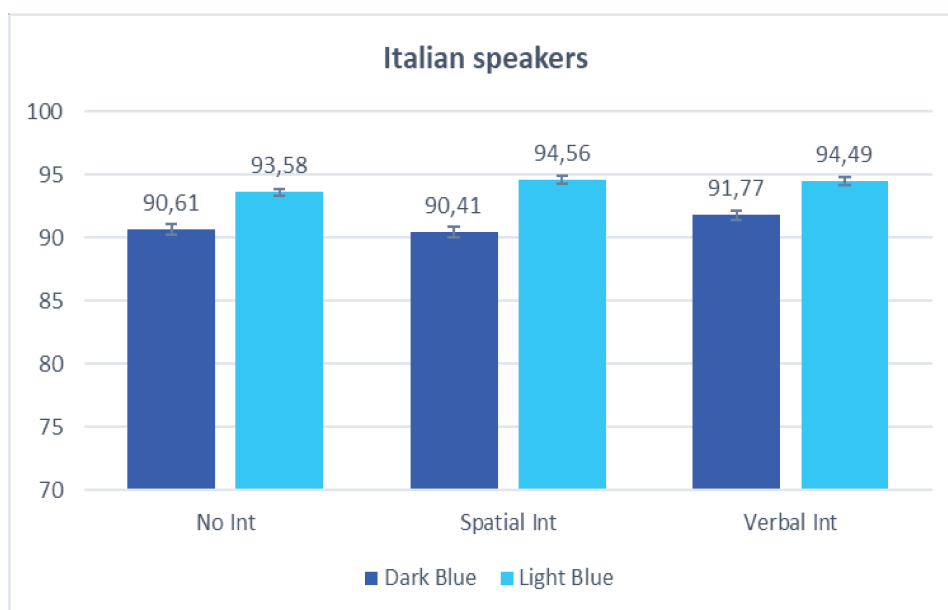


Graph 37: Global RT for each group of speakers without any distinction of Condition.

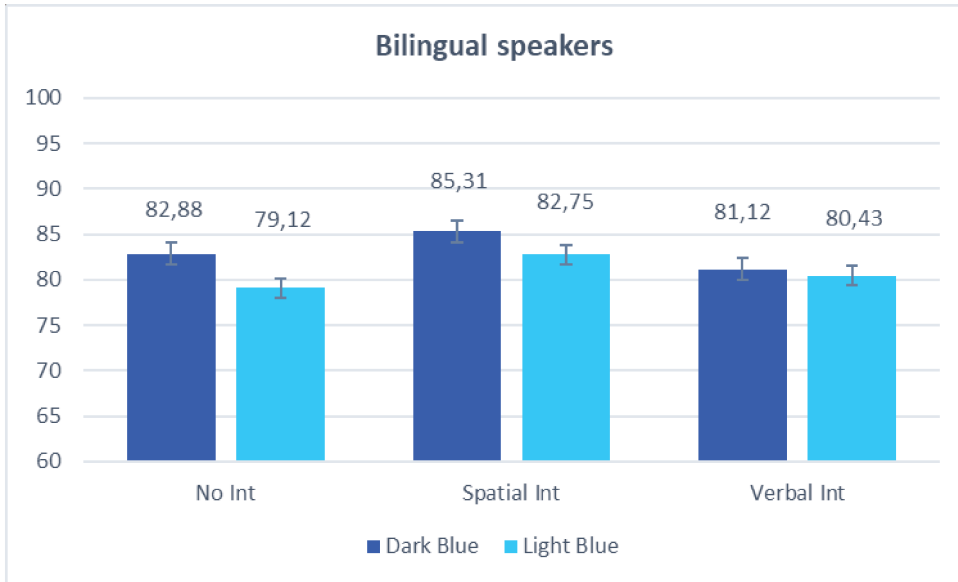
Mean Error Rate (in percentage) of the Color Patch Effect with Standard Error (SE) bars. For each group of participants, the two-way interactions between the color patch category (dark blue or light blue) and the experimental condition (No Interference Block, Spatial Interference Block and Verbal Interference Block) are displayed.



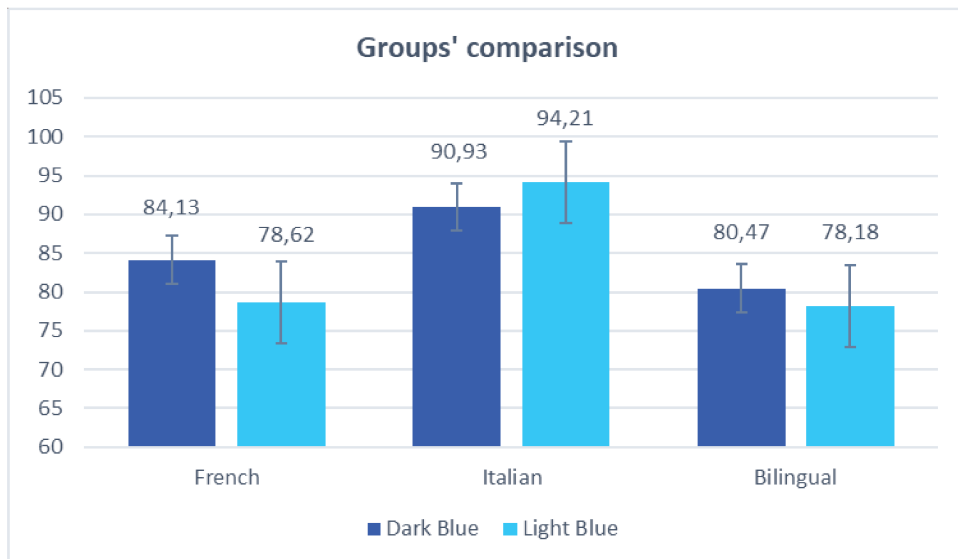
Graph 38: ACC for French monolingual speakers



Graph 39: ACC for Italian monolingual speakers



Graph 40: ACC for French-Italian Bilingual speakers



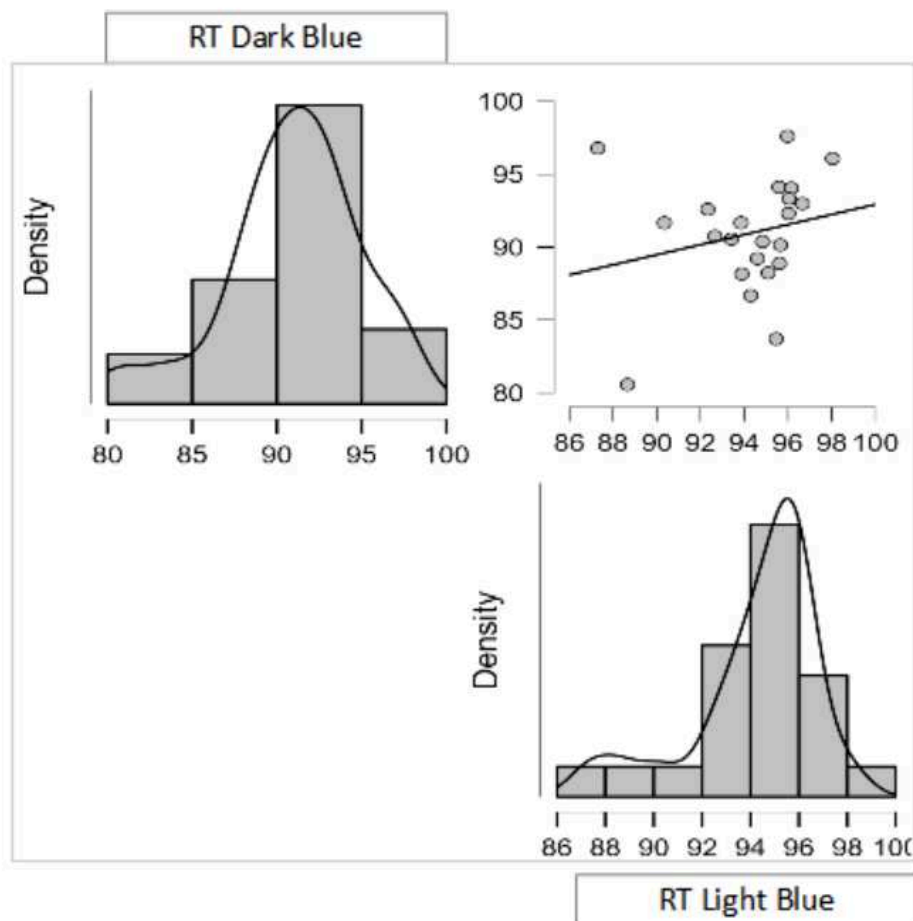
Graph 41: Global ACC for each group of speakers without any distinction of condition.

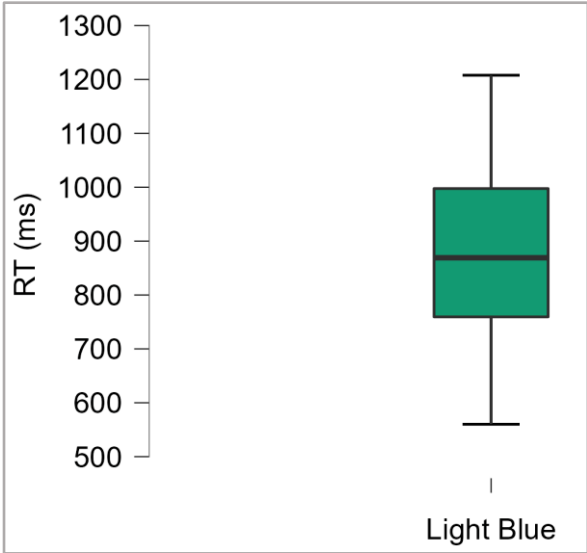
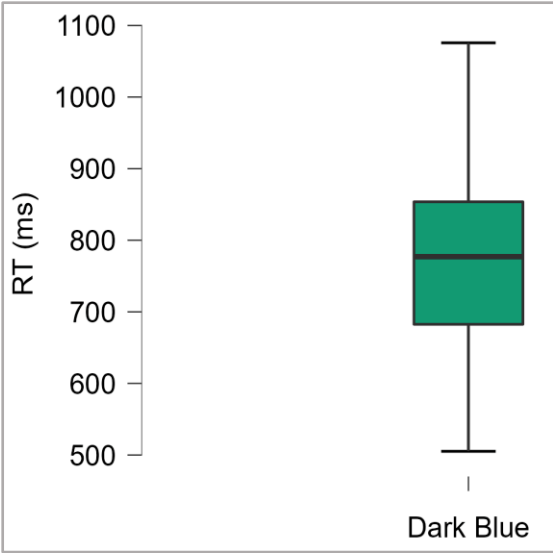
The Color Patch Effect in the Color Patch Effect Analysis

Distributional and Correlation plots with density and boxplots of significant results for the Color Patch Effect are displayed for the three participants' groups.

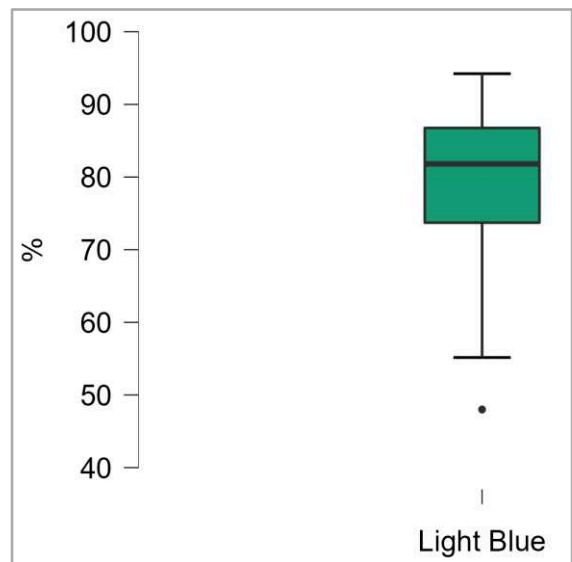
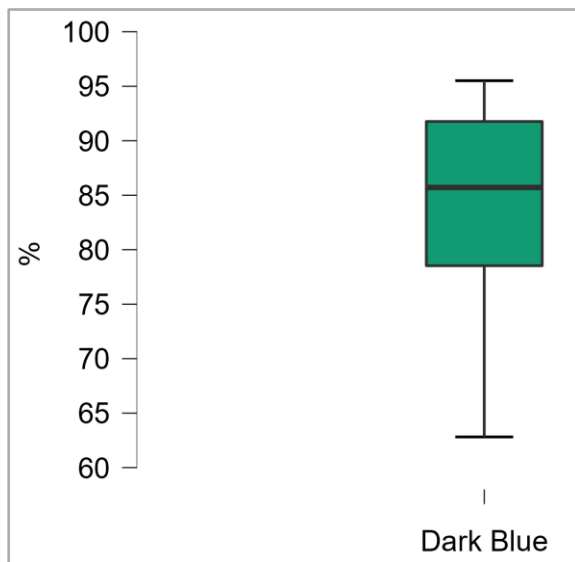
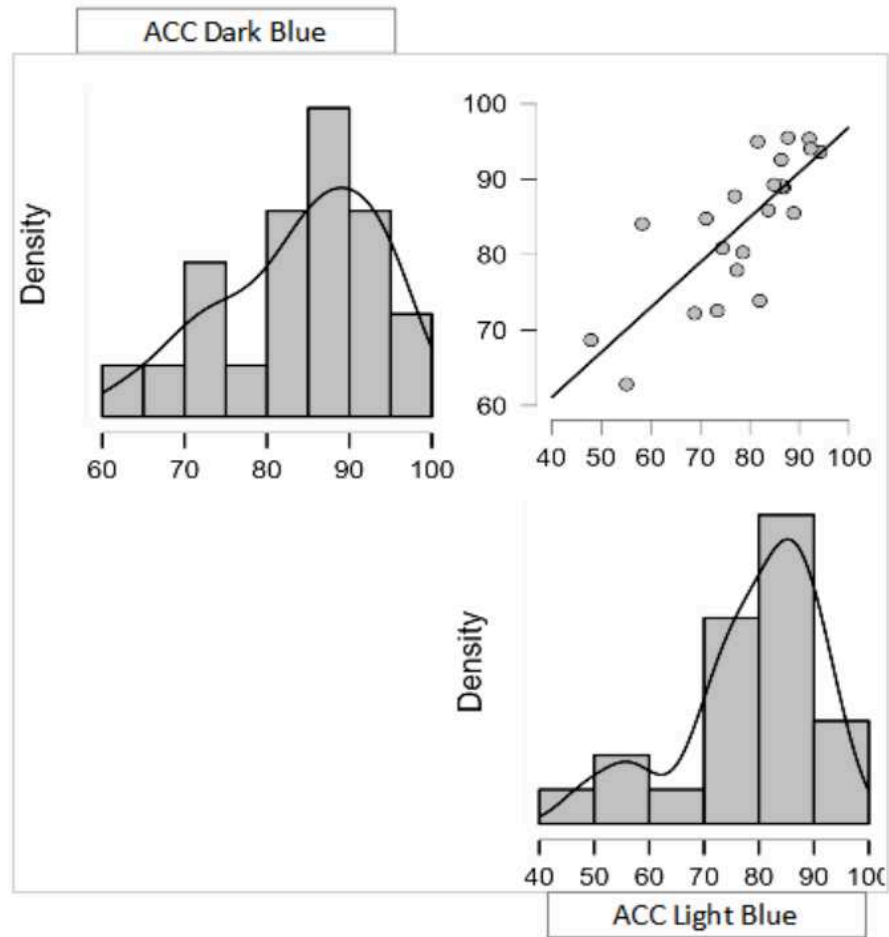
FRENCH MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Dark Blue vs Light Blue Patches:



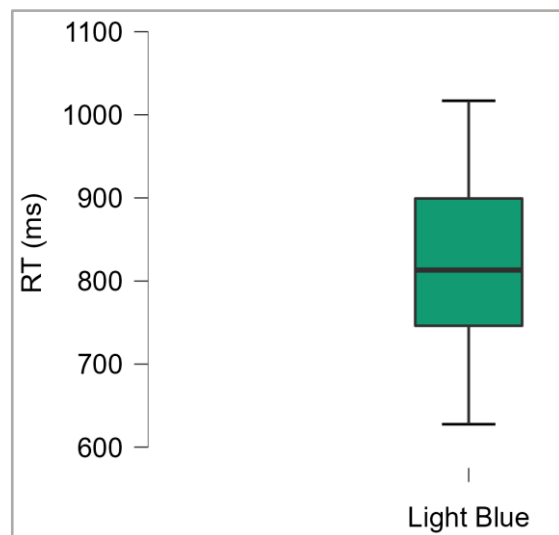
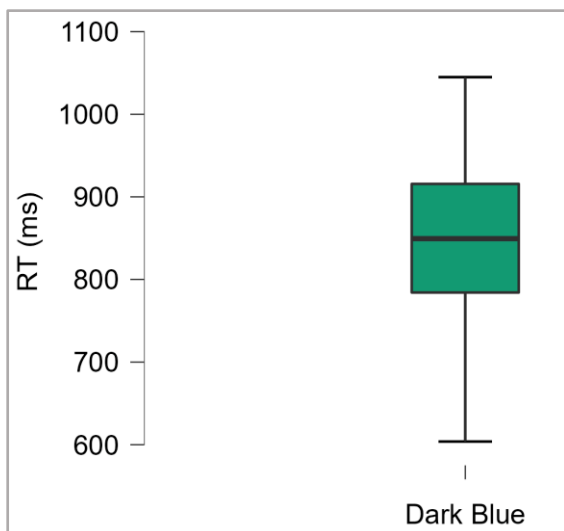
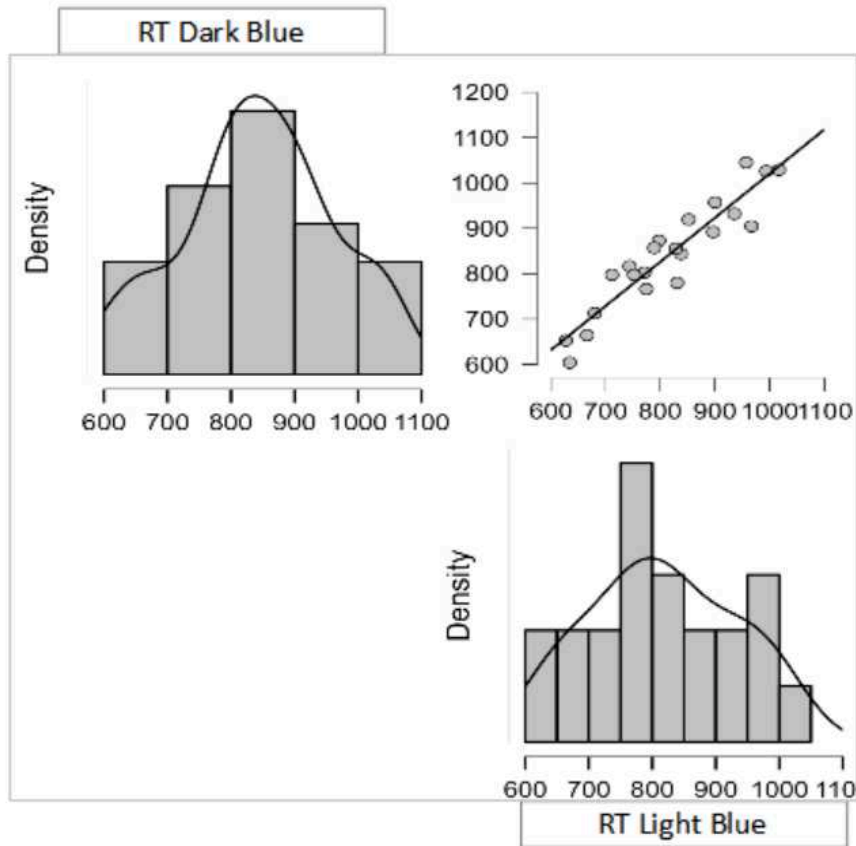


Mean Error Rate (in percentage) for Dark Blue vs Light Blue Patches:

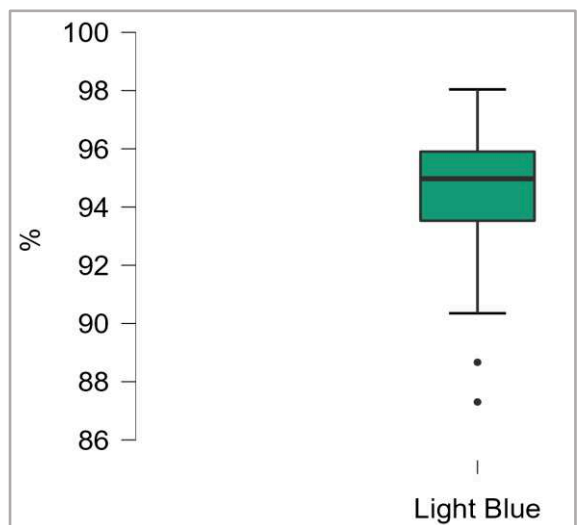
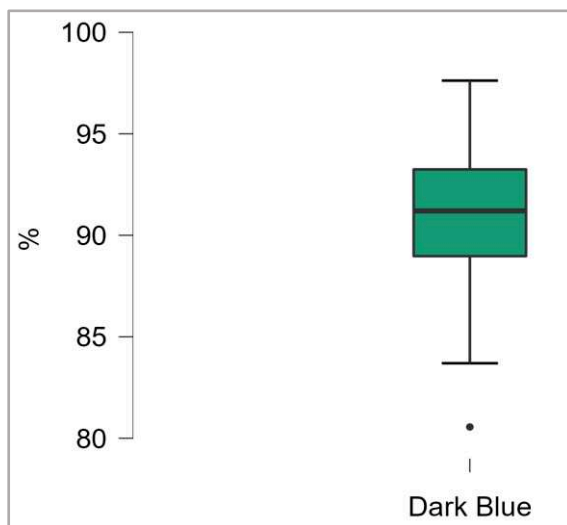
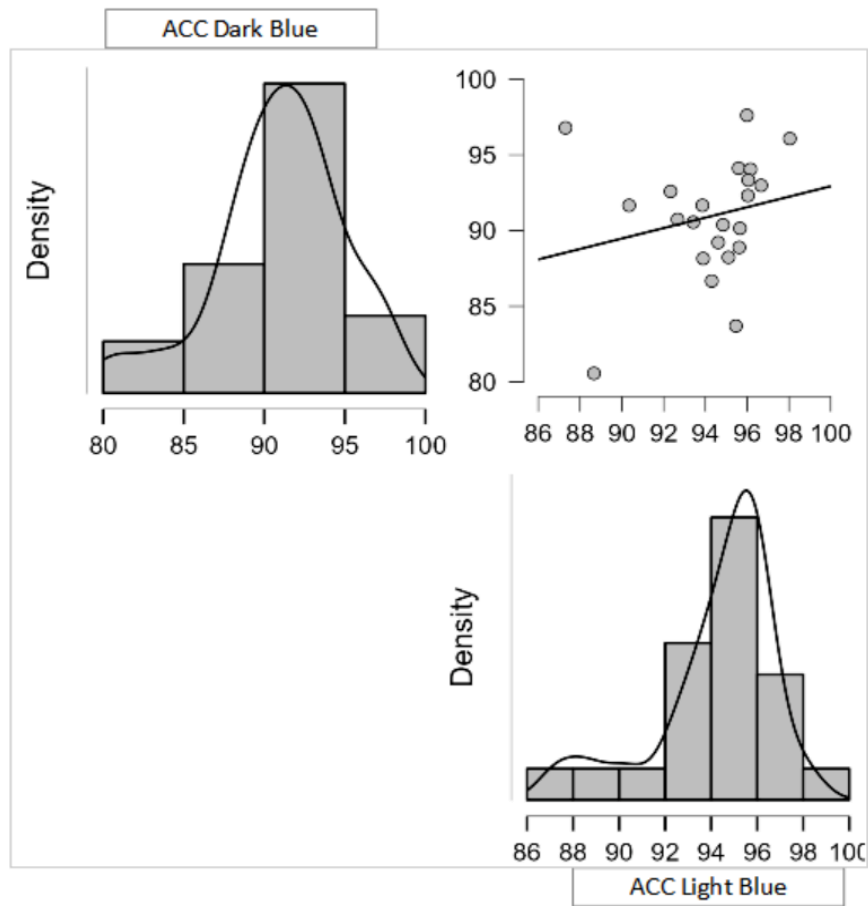


ITALIAN MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Dark Blue vs Light Blue Patches:

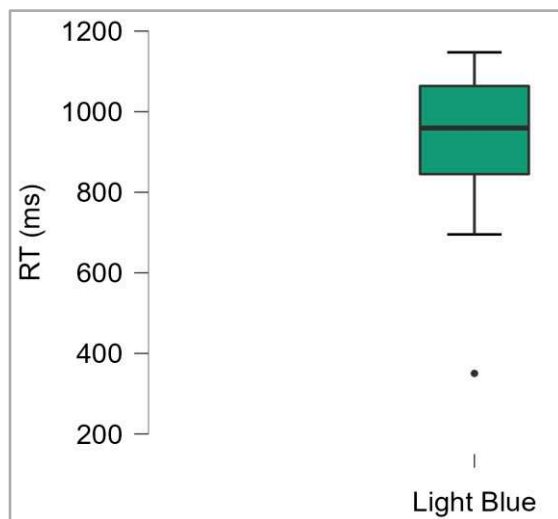
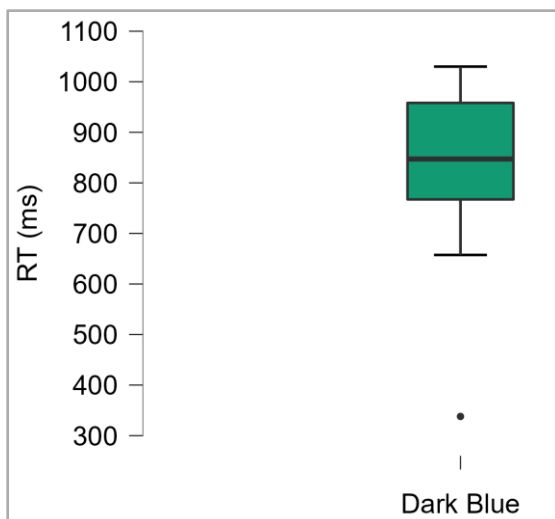
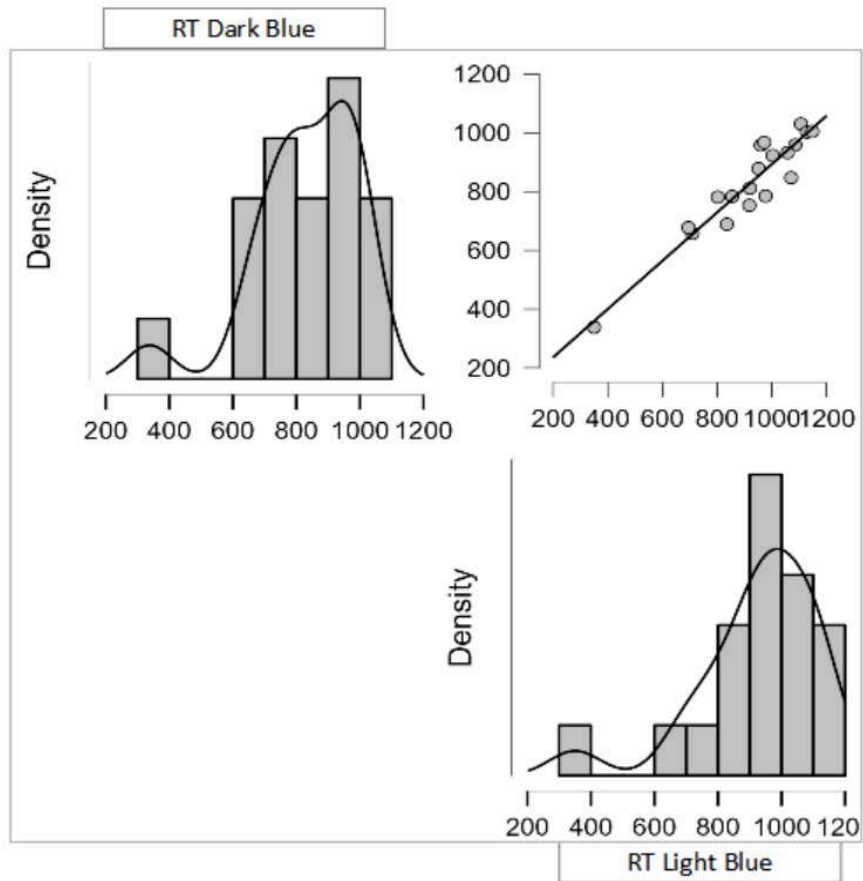


Mean Error Rate (in percentage) for Dark Blue vs Light Blue Patches:

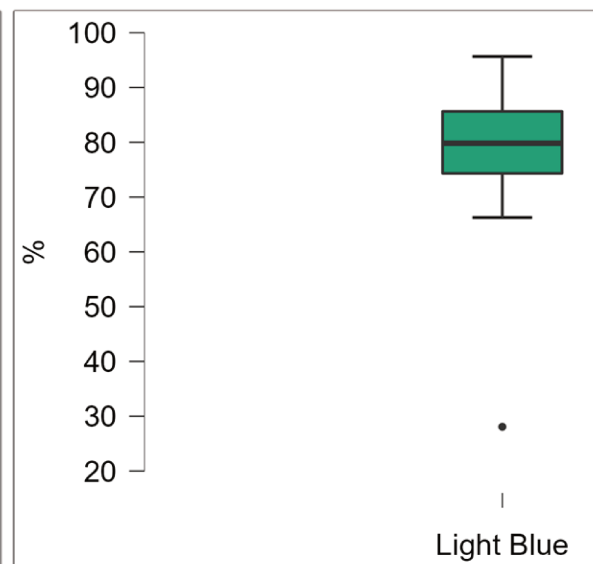
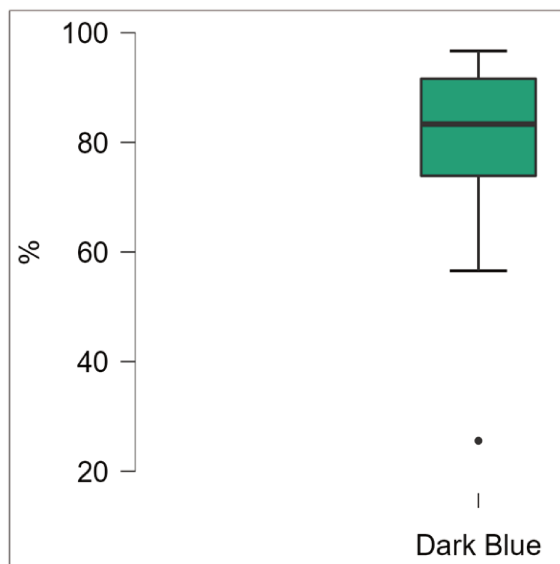
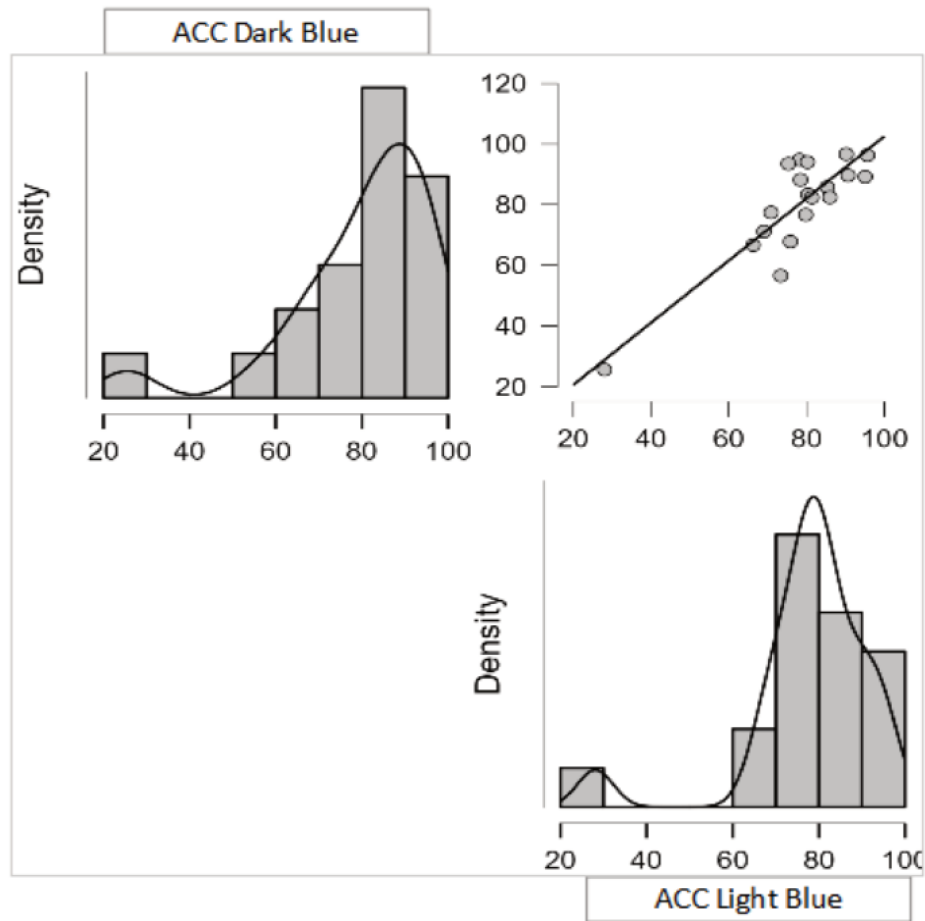


BILINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Dark Blue vs Light Blue Patches:

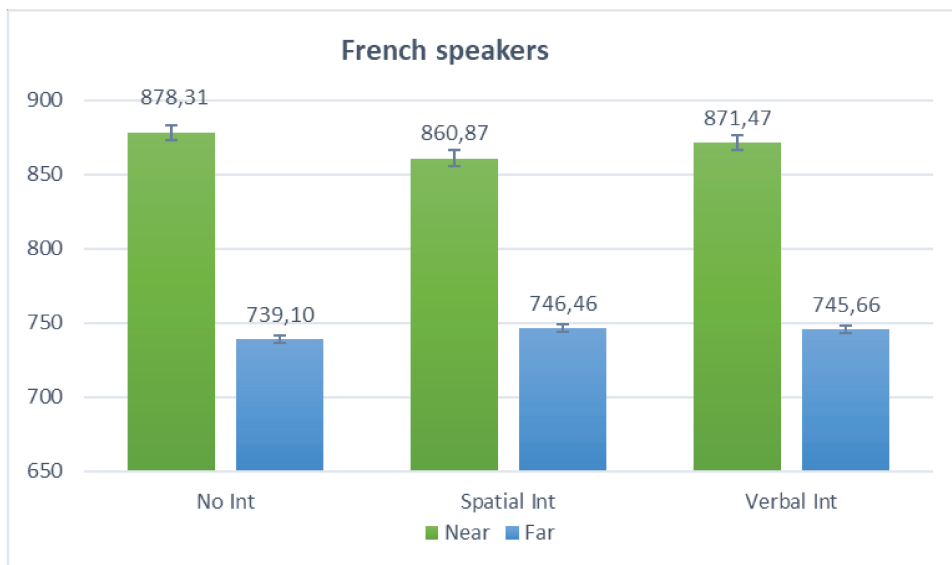


Mean Error Rate (in percentage) for Dark Blue vs Light Blue Patches:

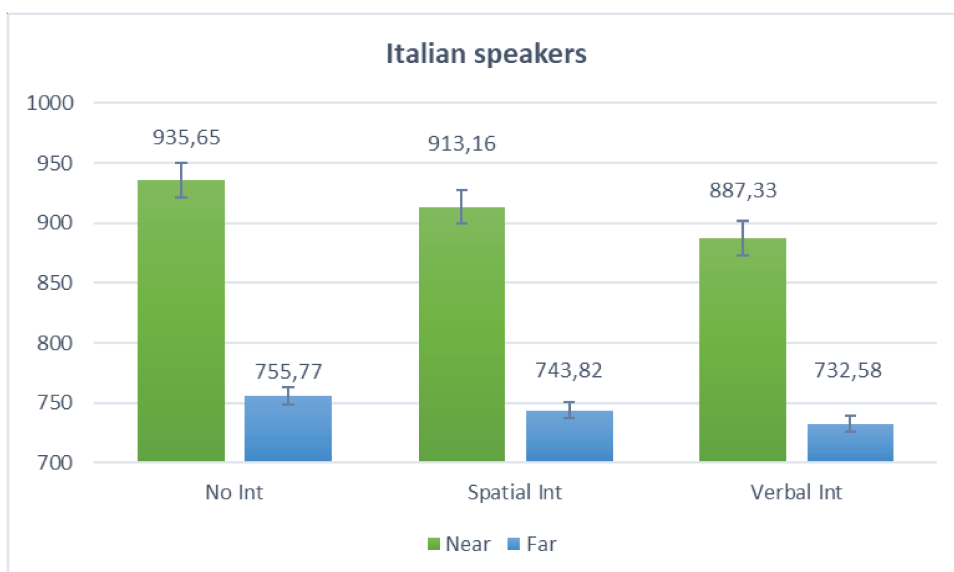


RTs and Accuracy for the Distance Effect

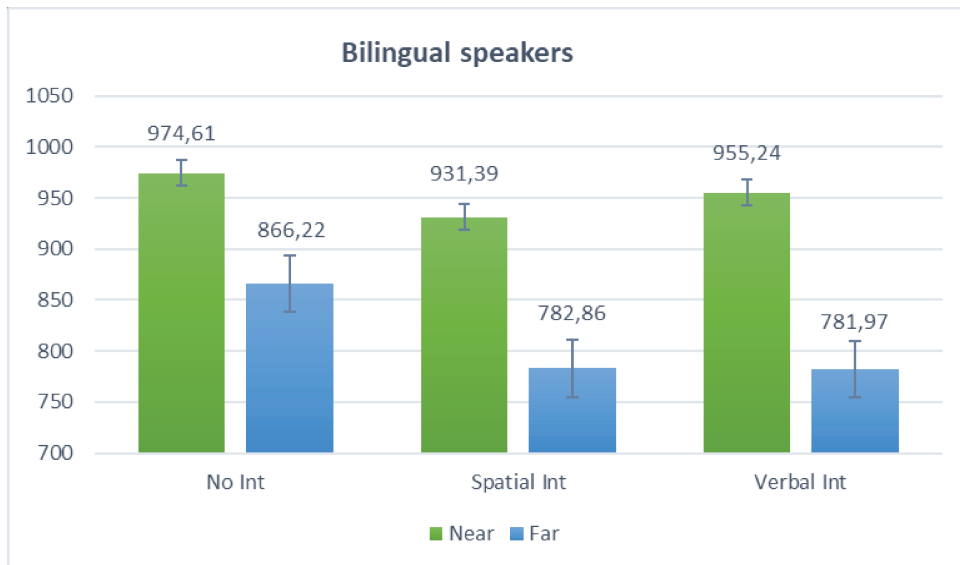
Mean Reaction Time (in milliseconds) of the Effect of Distance with Standard Error (SE) bars. For each group of participants, the two-way interactions between the color distance (near or far colours) and the experimental condition (No Interference Block, Spatial Interference Block and Verbal Interference Block) are displayed.



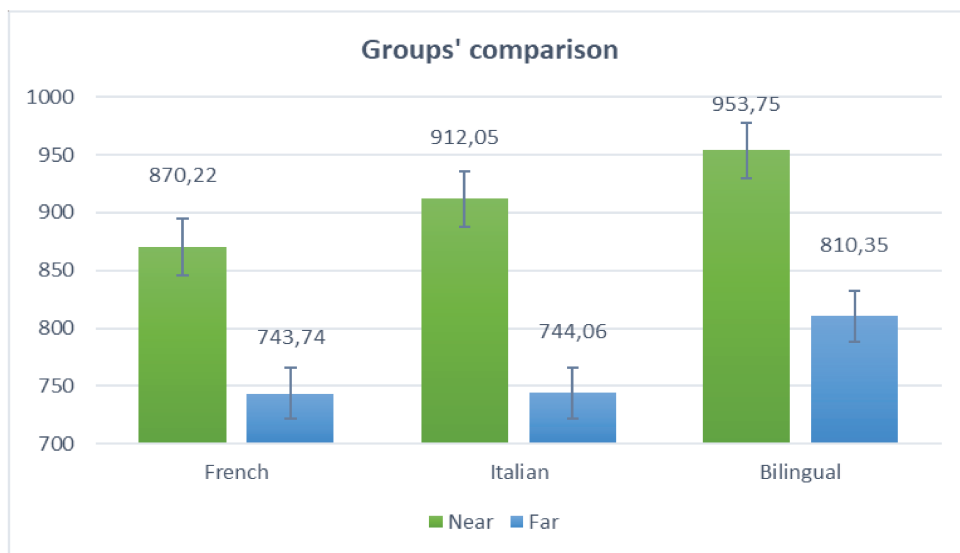
Graph 42: RTs for French monolinguals



Graph 43: RTs for Italian monolinguals

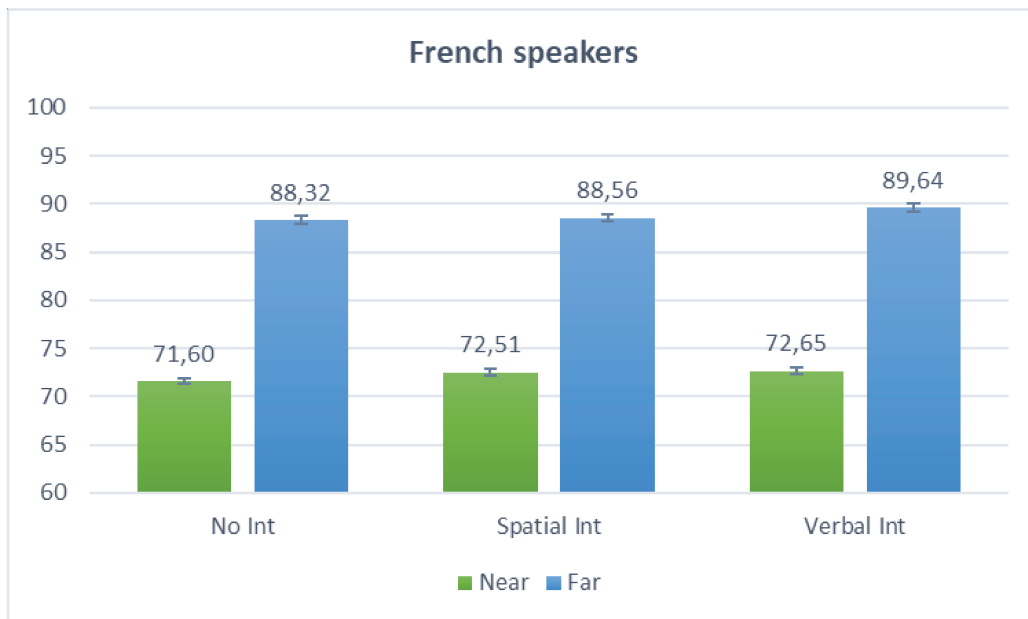


Graph 44: RTs for French-Italian Bilinguals speakers

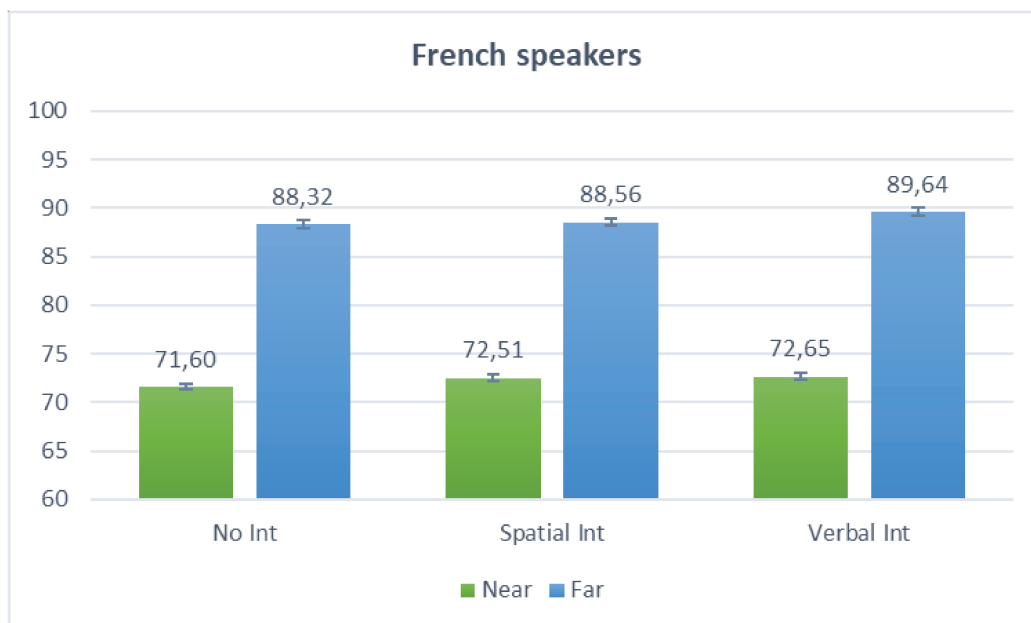


Graph 45: Global RT for each group of speakers without any distinction of Condition.

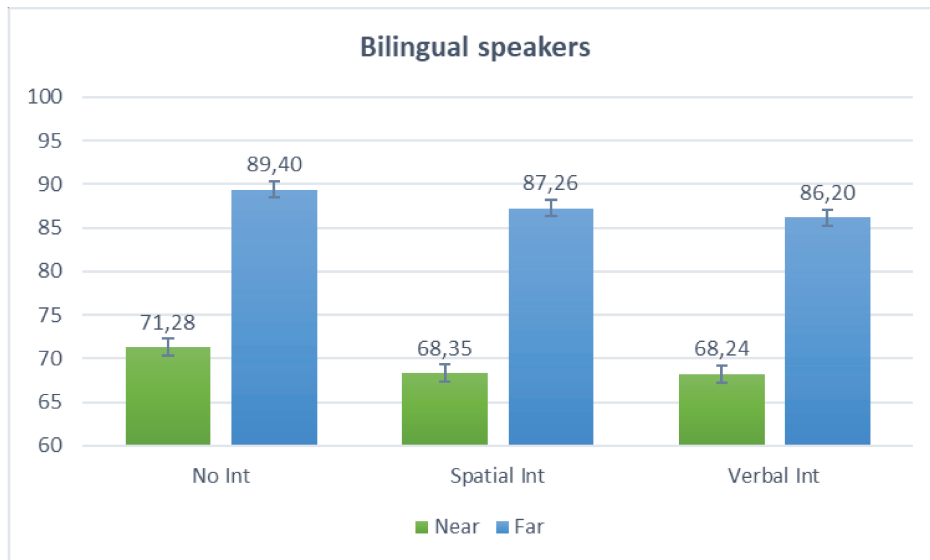
Mean Error Rate (in percentage) of the Effect of Distance with Standard Error (SE) bars. For each group of participants, the two-way interactions between the color distance (near or far colours) and the experimental condition (No Interference Block, Spatial Interference Block and Verbal Interference Block) are displayed.



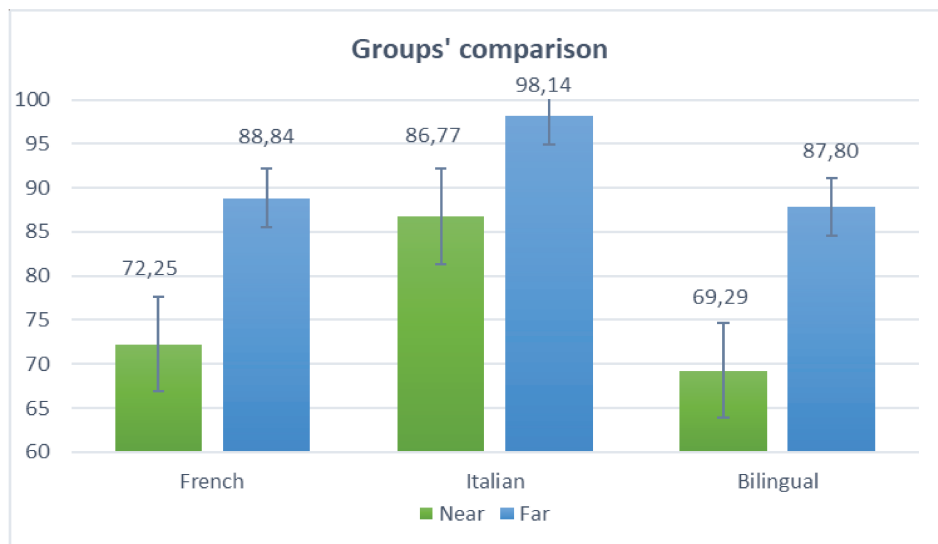
Graph 46: ACC for French monolingual speakers.



Graph 47: ACC for Italian monolingual speakers.



Graph 48: ACC for French-Italian Bilinguals speakers.



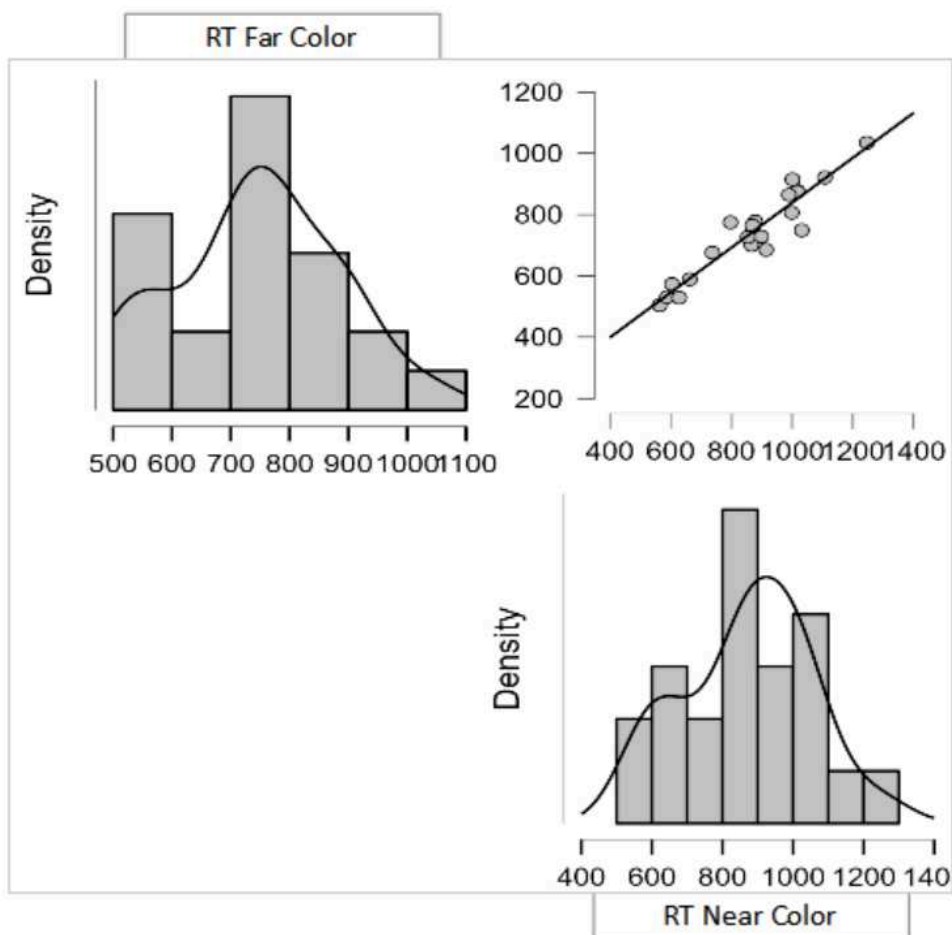
Graph 49: Global ACC for each group of speakers without any distinction of condition.

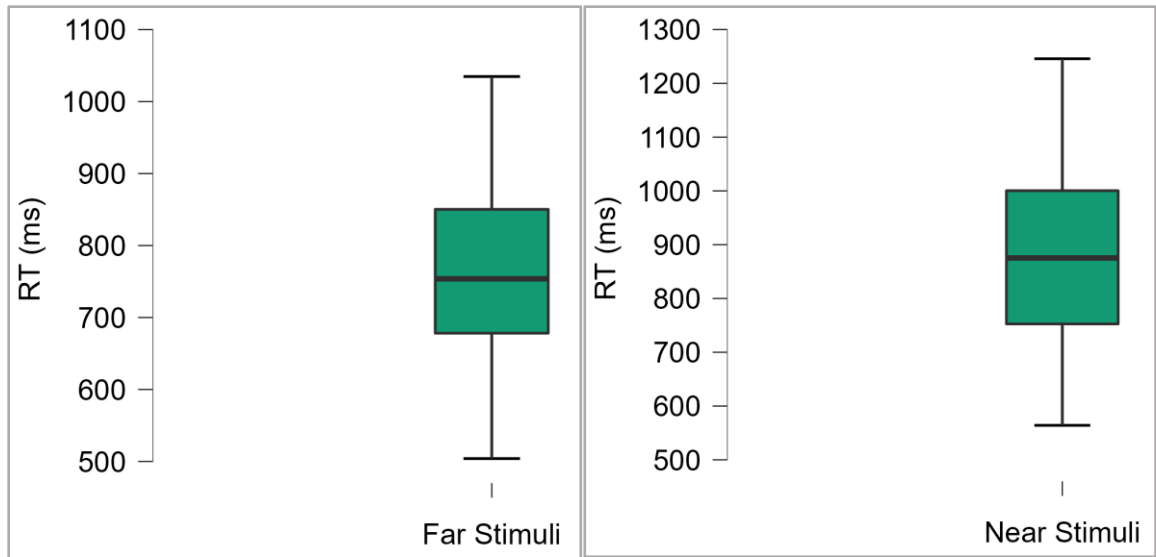
The Distance Effect in the Color Patch Effect Analysis

Distributional and Correlation plots with density and boxplots of significant results for the Distance Effect are displayed for the three participants' groups.

FRENCH MONOLINGUAL SPEAKERS

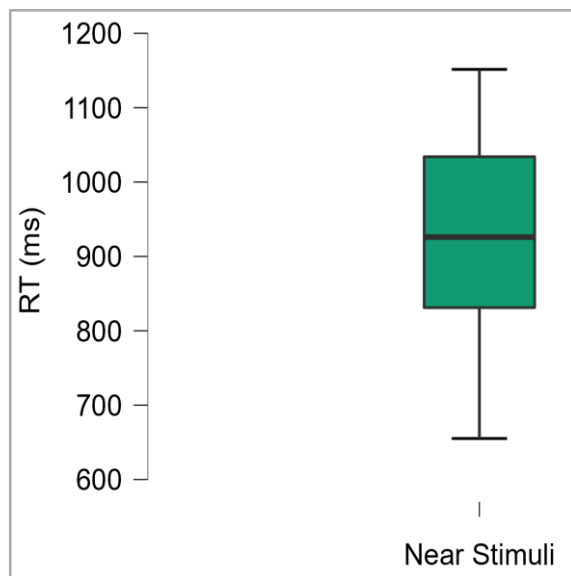
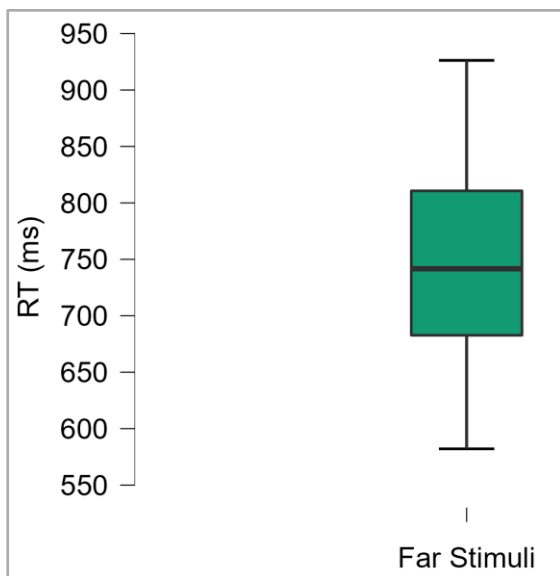
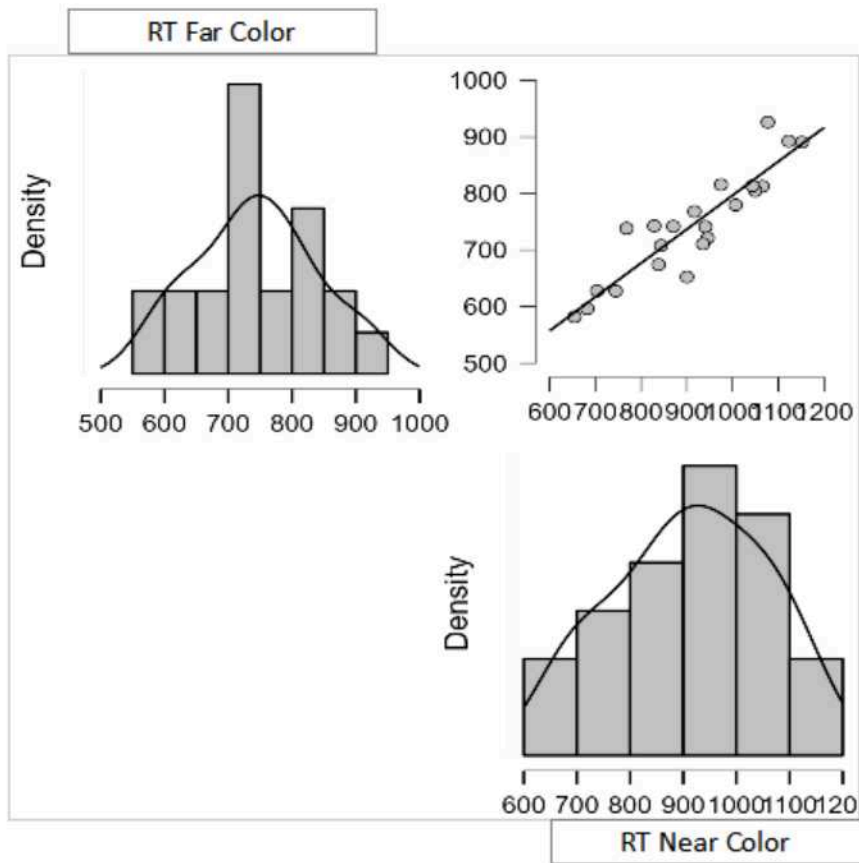
Mean Reaction Time (in milliseconds) for Far and Near color stimuli:





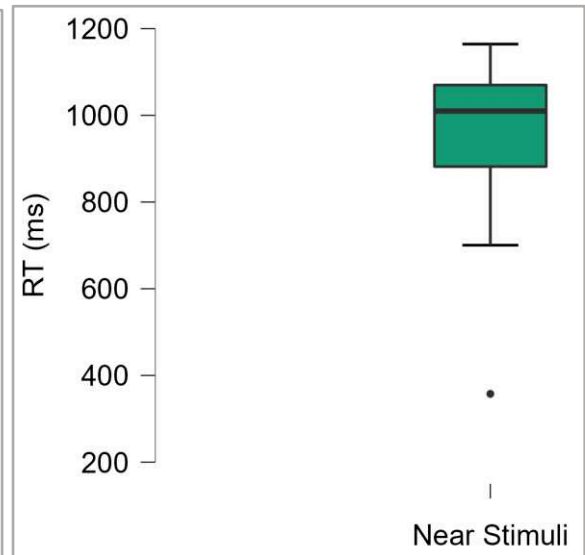
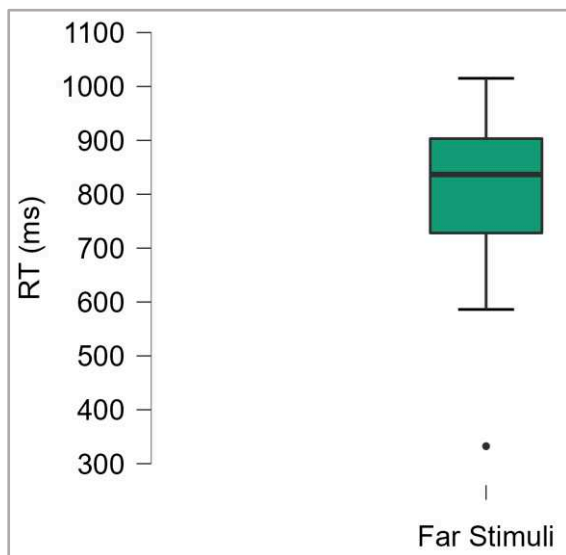
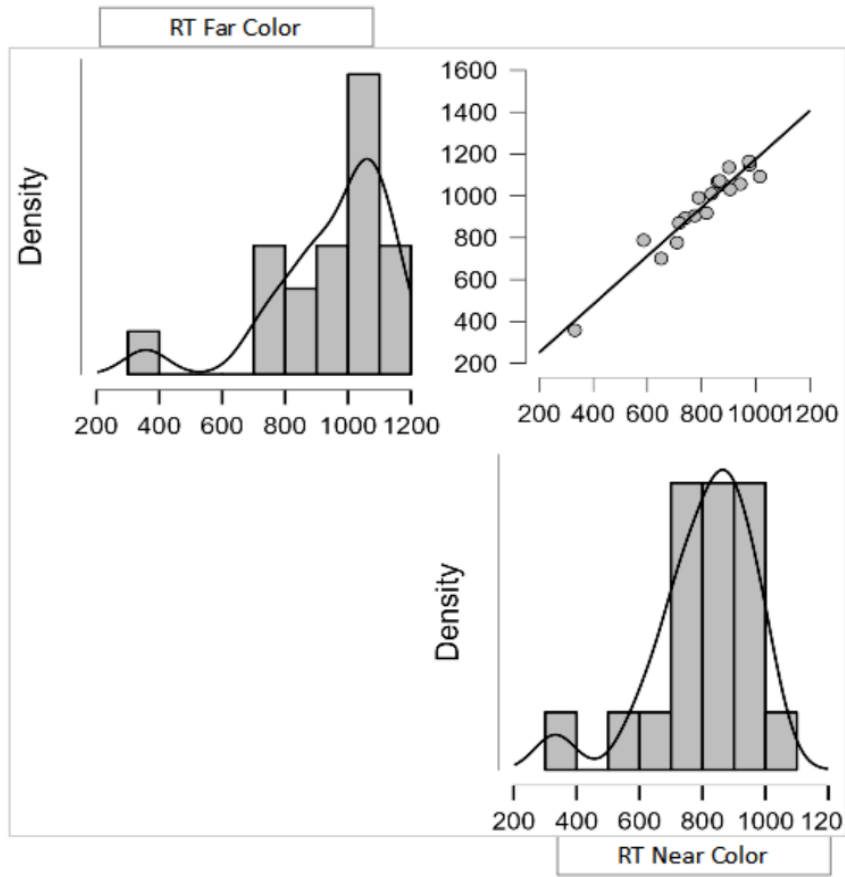
ITALIAN MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Far and Near color stimuli



BILINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Far and Near color stimuli



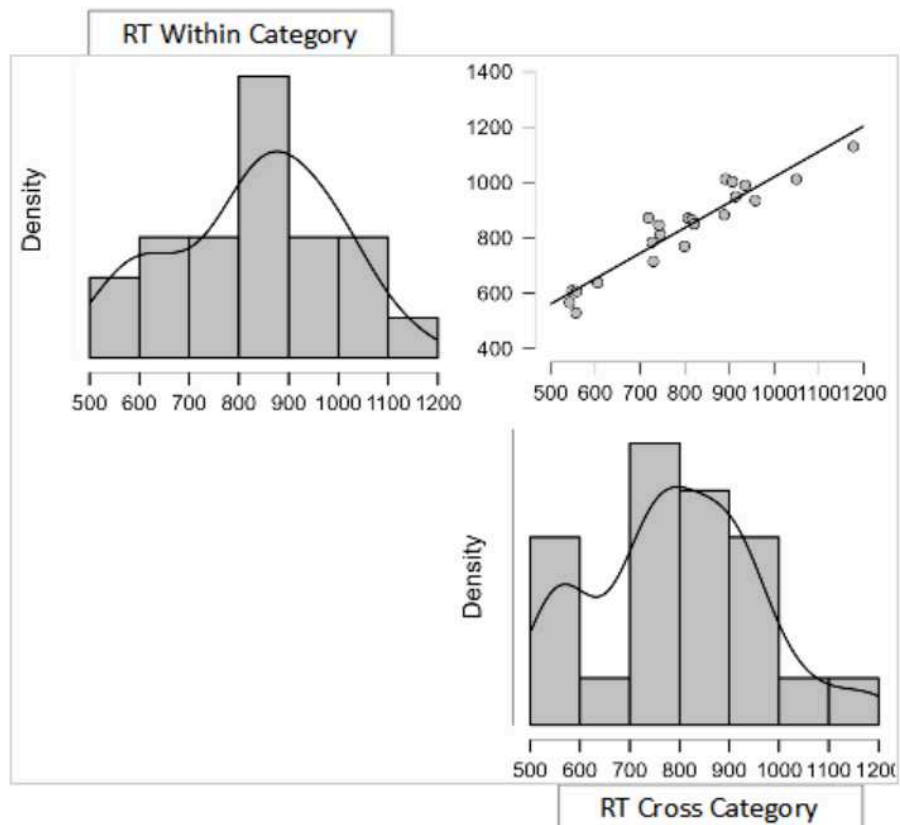
Category Advantage

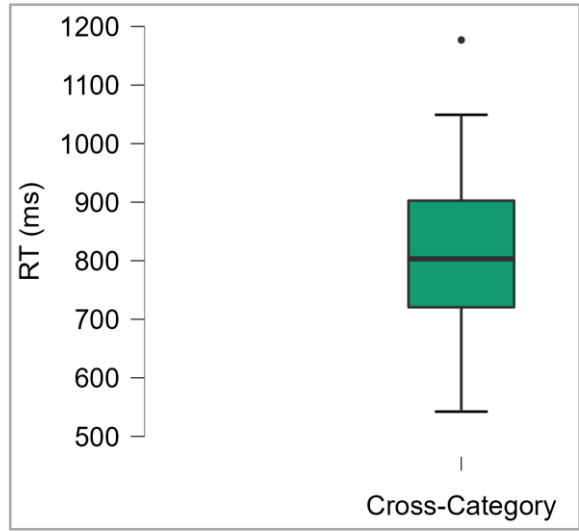
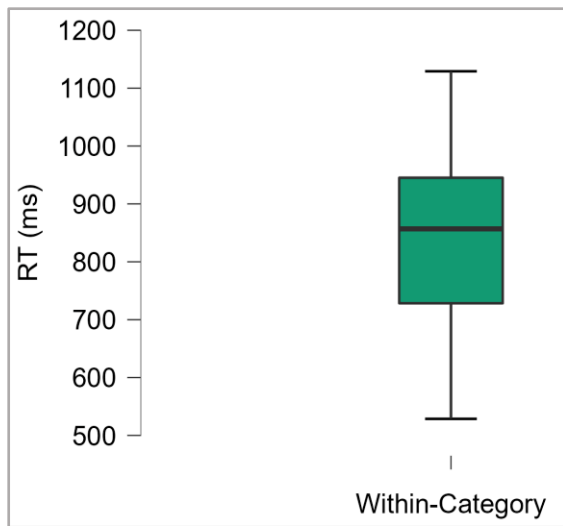
The Category Effect in the Category Advantage Analysis

Distributional and Correlation plots with density and boxplots of significant results for the Category Effect in the Category Advantage analysis: Mean Reaction Time and Mean Error Rate are displayed for the three participants' groups.

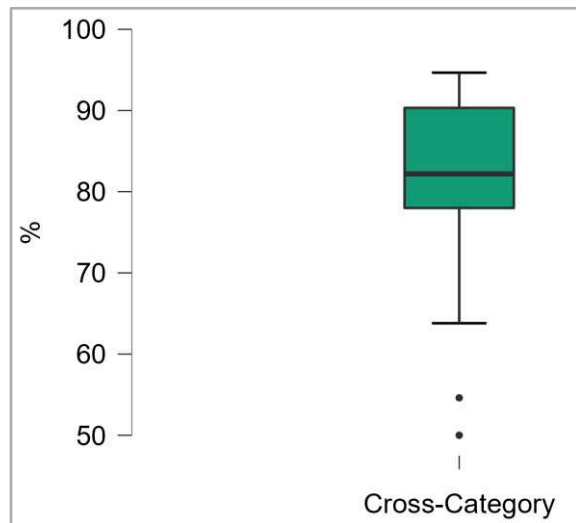
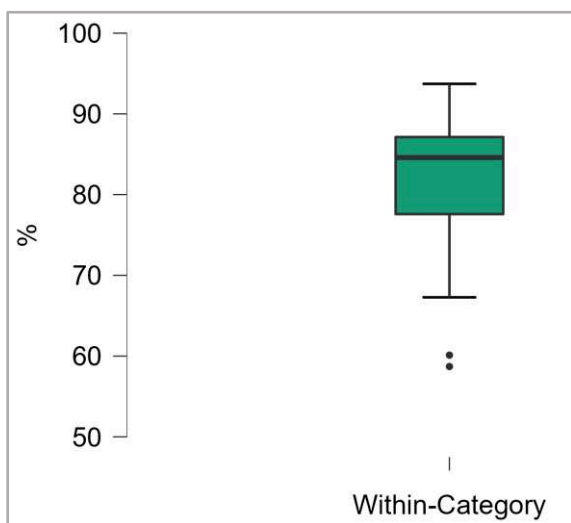
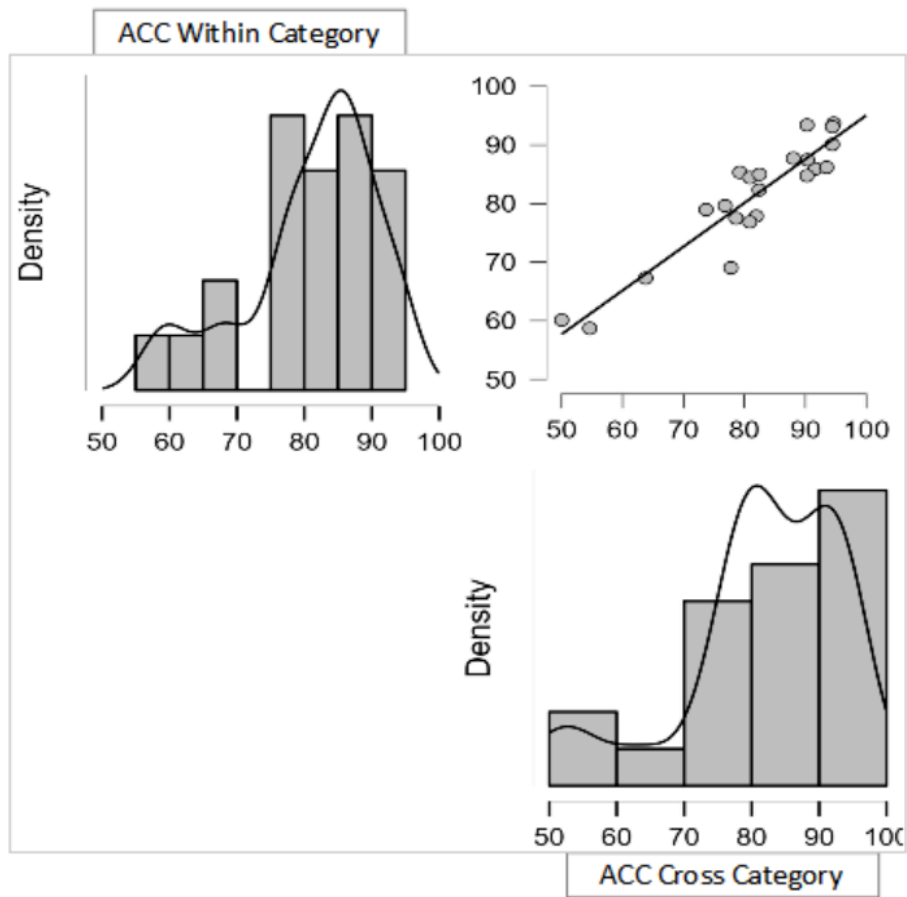
FRENCH MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for within-category and cross-category stimuli



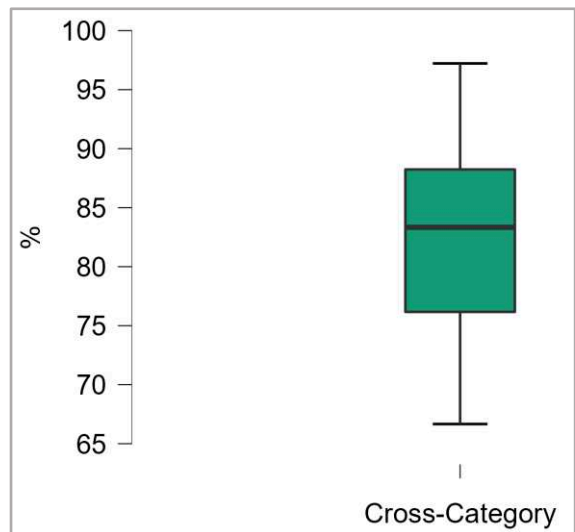
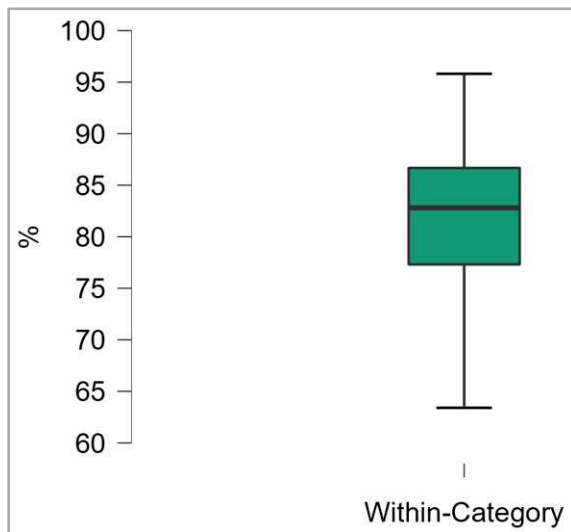
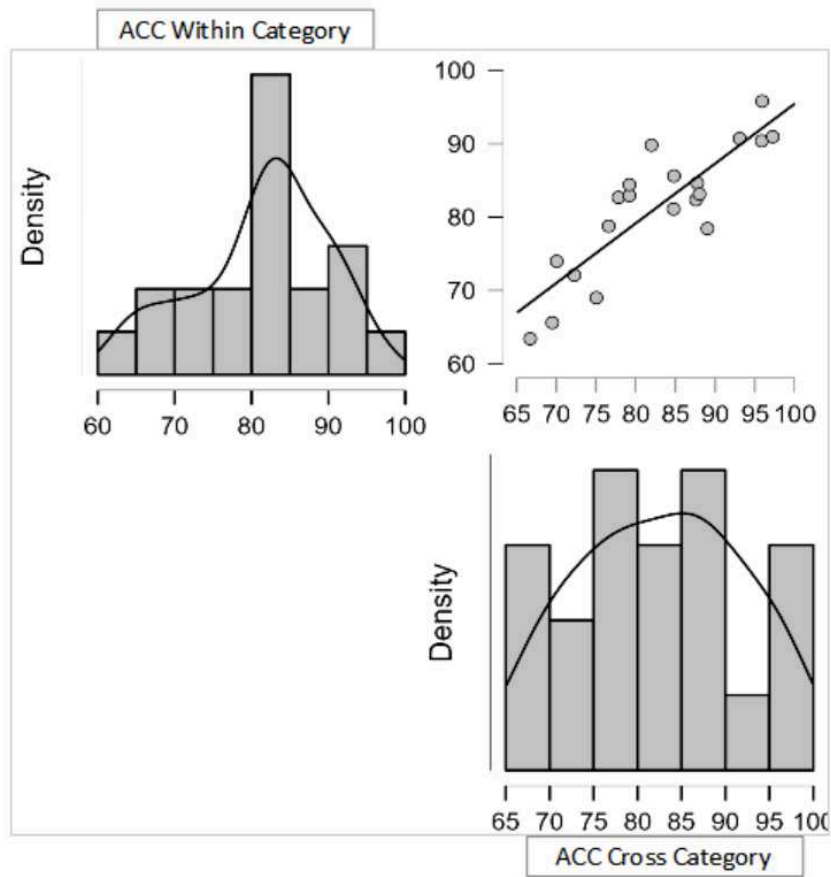


Mean Error Rate (in percentage) for within-category and cross-category stimuli



BILINGUAL SPEAKERS

Mean Error Rate (in percentage) for within-category and cross-category stimuli

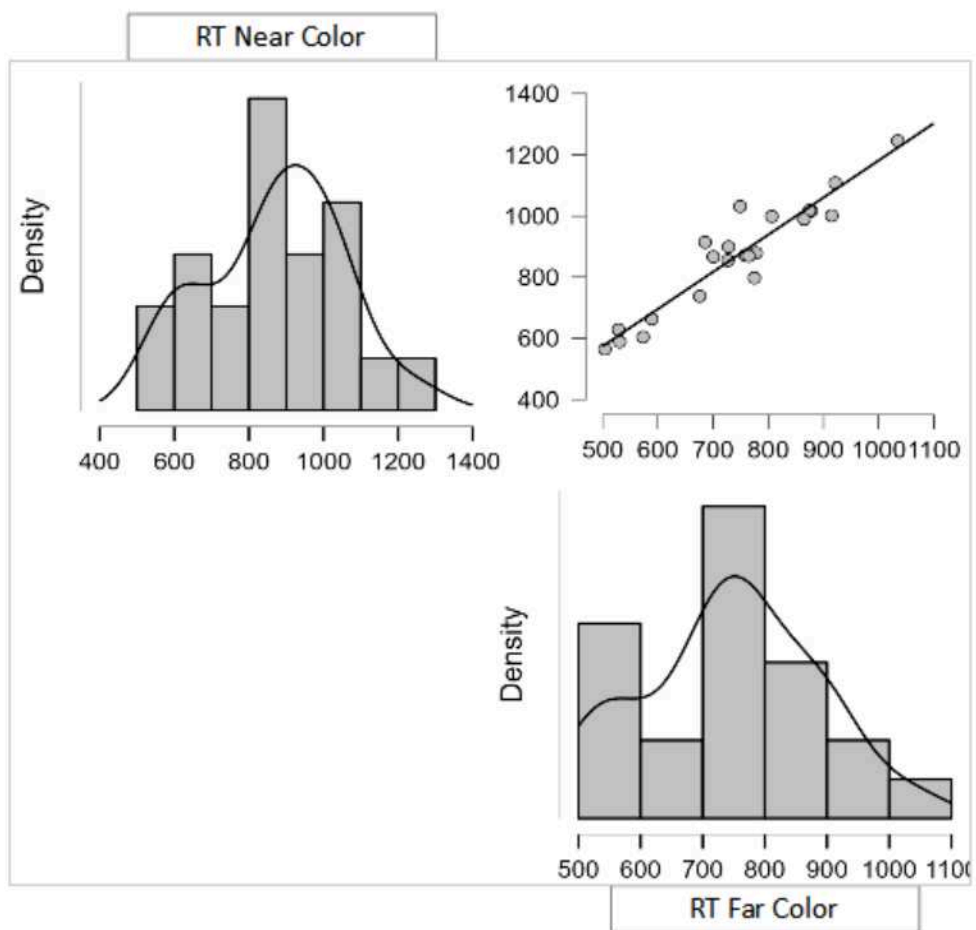


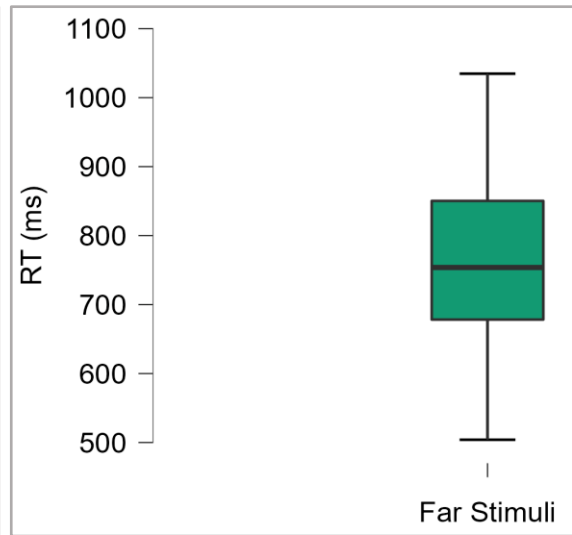
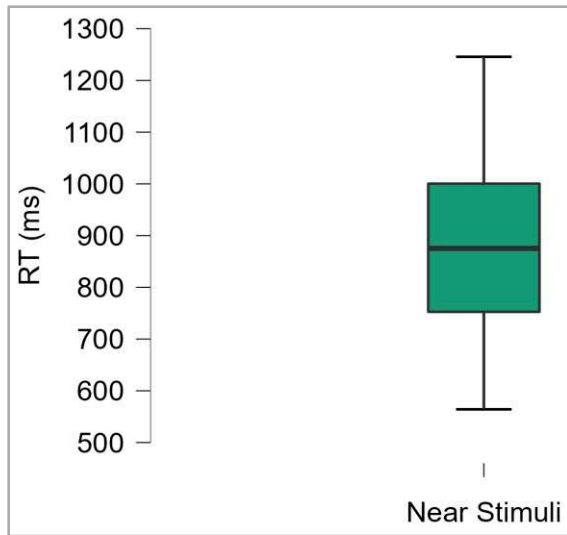
The Distance Effect in the Category Advantage Analysis

Distributional and Correlation plots with density and boxplots of significant results for the Distance Effect in the Category Advantage analysis: Mean Reaction Time and Mean Error Rate are displayed for the three participants' groups.

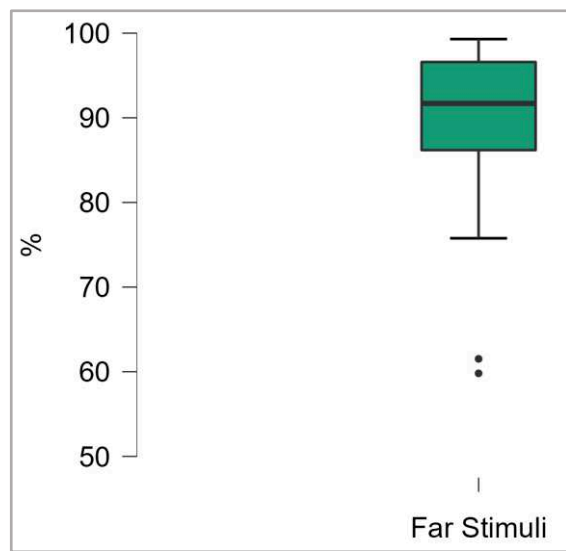
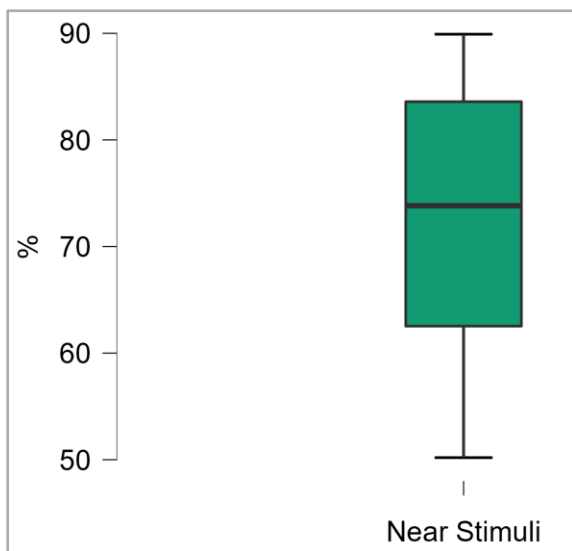
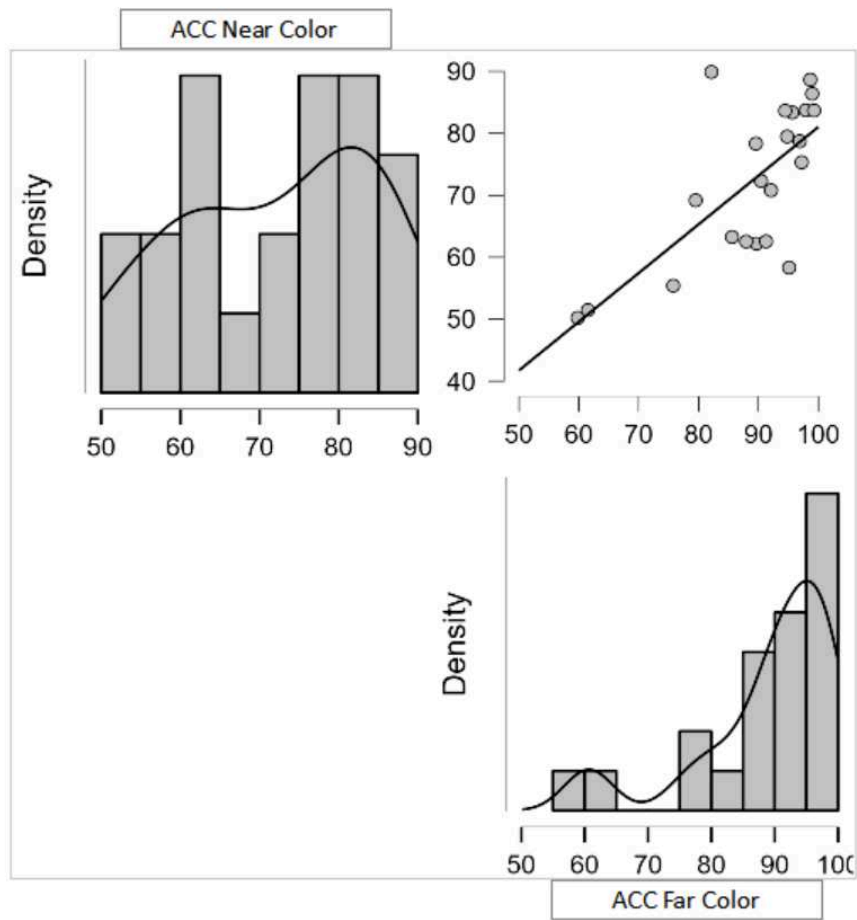
FRENCH MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Near and Far color stimuli



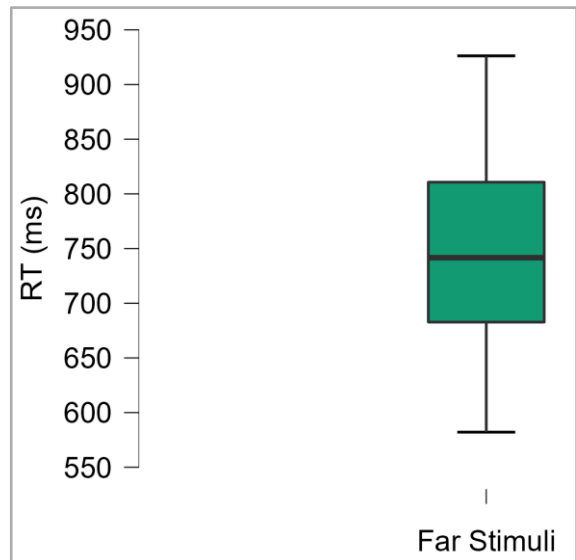
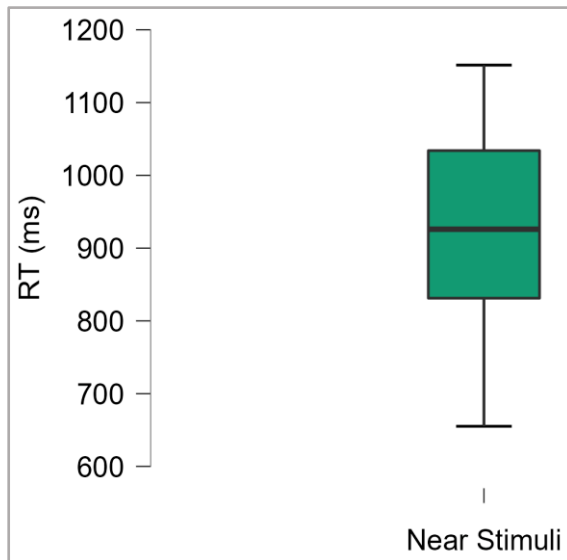
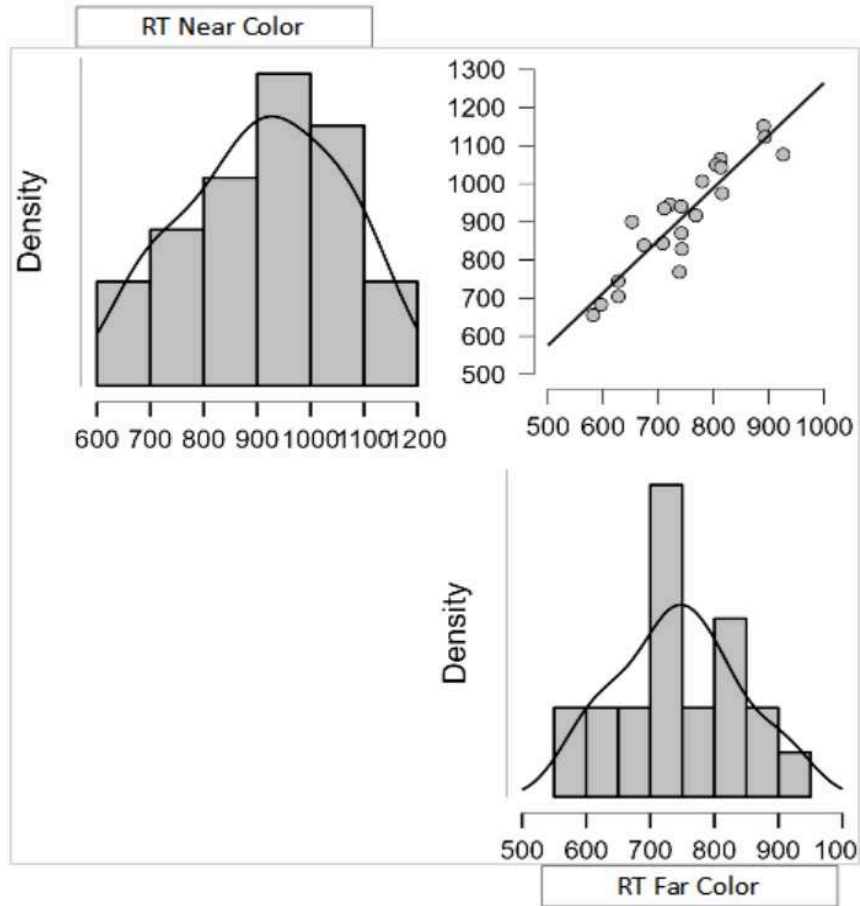


Mean Error Rate (in percentage) for Near and Far color stimuli

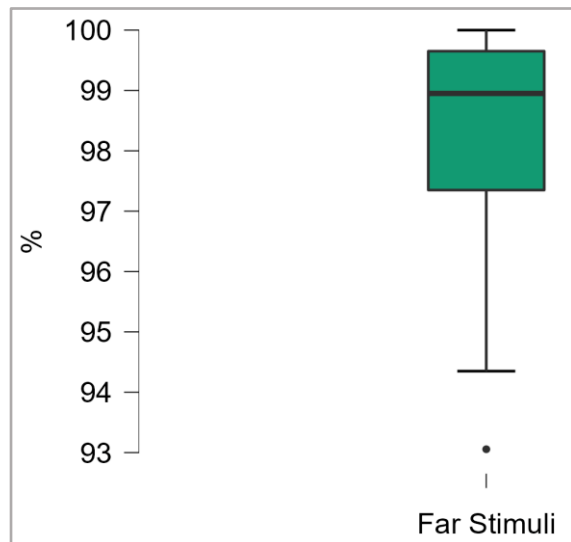
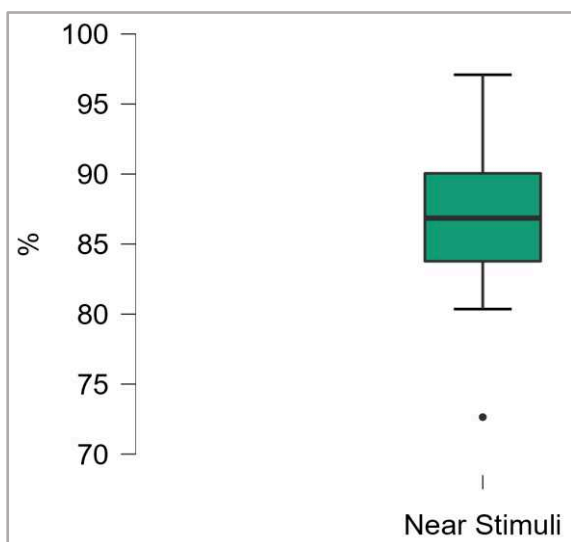
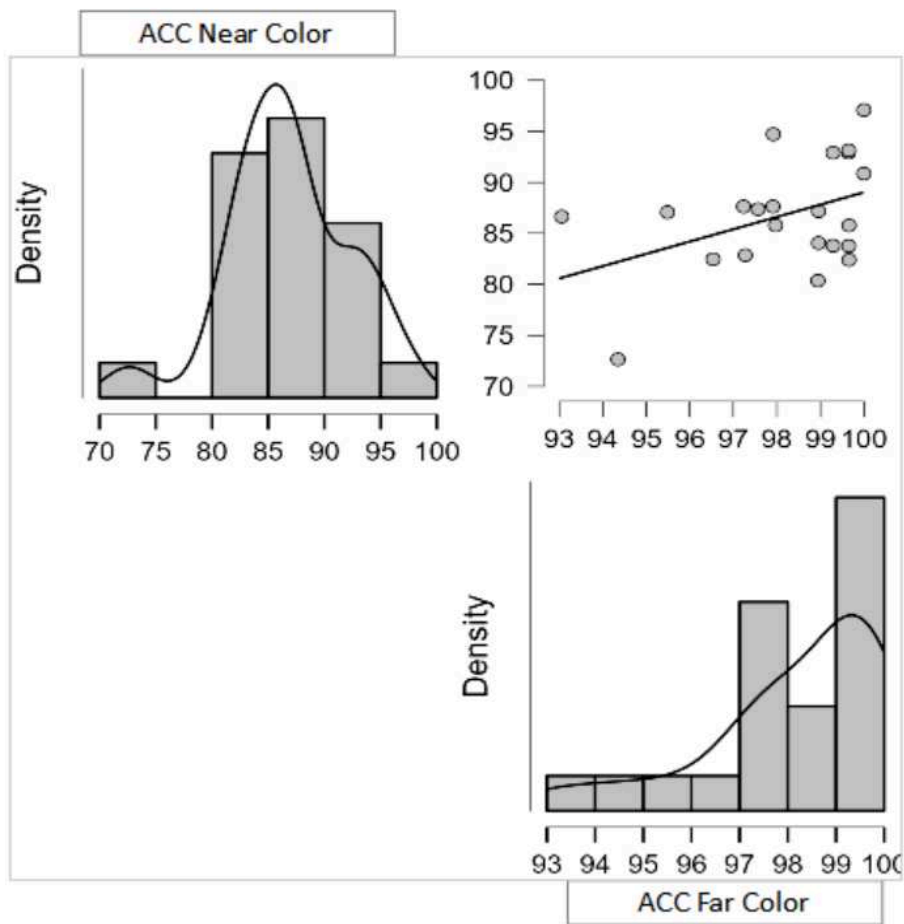


ITALIAN MONOLINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Near and Far color stimuli:

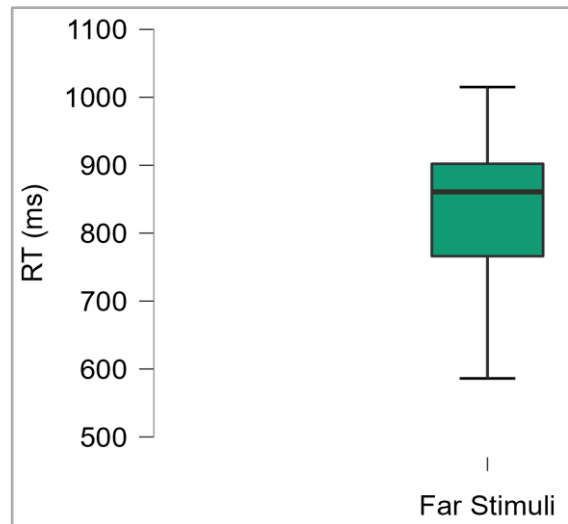
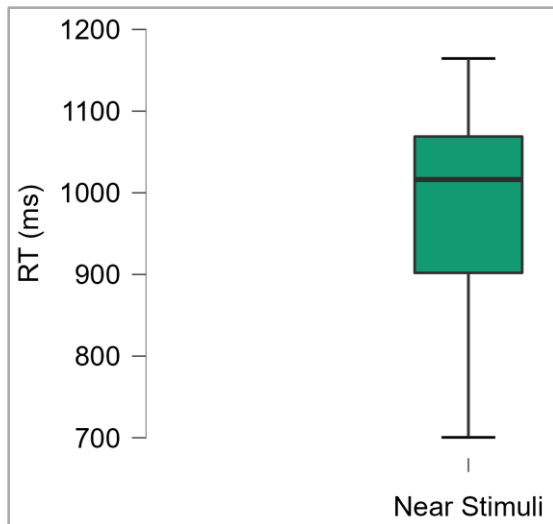
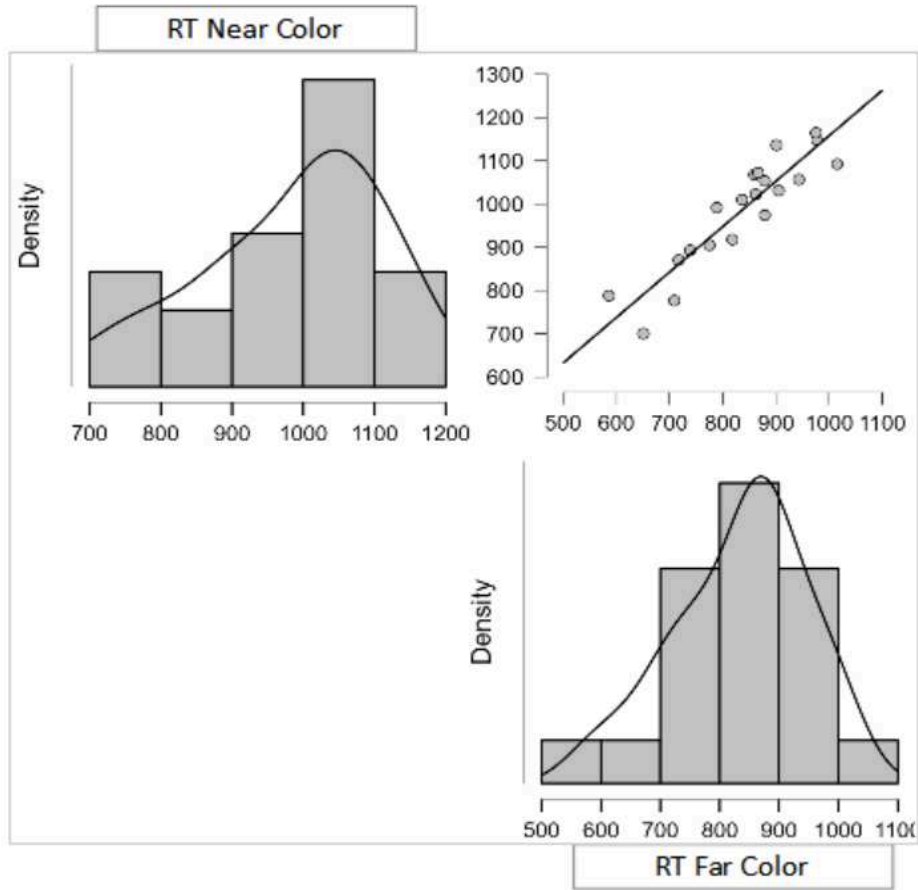


Mean Error Rate (in percentage) for Near and Far color stimuli:



BILINGUAL SPEAKERS

Mean Reaction Time (in milliseconds) for Near and Far color stimuli:



Mean Error Rate (in percentage) for Near and Far color stimuli:

