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The perceptual and cognitive markers of smells' naturalness

Morgane Dantec

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Morgane Dantec

**The perceptual and cognitive markers
of smells' naturalness**
*(Marqueurs perceptifs et cognitifs de la naturalité des
odeurs)*

Devant le jury composé de :

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Amat, Corine , Maître de Conférences, Université Lyon 1	Examinatrice
Dalton, Pamela , Directrice de Recherche, Monell Chemical Senses center (USA),	Examinatrice
Zampini, Massimiliano , Full Professor, University of Trento (Italie)	Rapporteur
Bensafi, Moustafa , Directeur de Recherche, CNRS UMR 5292	Directeur de thèse
Lafraire, Jérémie , Professeur Associé, Institut Paul Bocuse	Co-directeur de thèse
Zellner, Debra , Professor Emeritus, Montclair State University,	Invitée
Allain, Hélène , Responsable Industriel, V. Mane Fils	Invitée

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ABSTRACT

Nowadays, there is a growing interest in naturalness. Natural products are perceived as superior to non-natural products on many aspects, such as the impact on health or the environment. Beyond marketing considerations, studies in neuropsychology and neuroscience have shown the relevance of the natural/ human-made distinction for human cognition.

Among the different ways to study naturalness, the study of sensory markers of naturalness, and especially the olfactory characteristics, seems to be a fruitful, though under researched, avenue. Indeed, from an industry point of view, there is a strong stake at meeting consumer's sensory expectations about the products labeled as natural. From a research perspective, as olfaction has some peculiarities compared to other sensory modality, the study of the naturalness of odors could provide new elements to better understand the perception of naturalness. The objective of our research was therefore to identify the sensory and cognitive markers of naturalness in the olfactory domain.

In our research, we dealt with three major difficulties: naturalness is a vague and polysemous concept, different levels of analysis of smell perception have to be distinguished and considered to study olfactory perception, and the strong inter-individual variability intervening on the two previous elements.

A review of the literature on the notion of naturalness allowed us to precise the meaning of naturalness. Indeed, we provided a working definition according to which naturalness is characterized by an absence of human influence. Then, by studying the available knowledge on olfactory perception, we identified three relevant levels of analysis to study the olfactory perception of odors: the physical source, perceptual and cognitive levels. In our research, we sought to determine the respective contributions of these three levels to the perception of the naturalness of odors. Moreover, during our research, we took into account the inter-individual variability regarding naturalness perception and attitudes.

We conducted four studies. The Study 1 aimed to develop an attitudinal scale able of measuring inter-individual variability in attitudes towards naturalness. The objective was also to test to what extent this attitudinal variability could explain part of the interindividual variability in the perception of the naturalness of odors (Studies 3 and 4). Studies 2 and 3 investigated the factors underlying olfactory perception of naturalness, either by studying expectations about the sensory characteristics of natural products (Study 2) or by assessing the properties of odors and

their relationship to the perception of naturalness (Study 3). Finally, Study 4 focused on the crossmodal aspect of the naturalness of odors by examining the association of naturalness meaning between vision and olfaction.

Results of study 3 revealed that participants did not discriminate between odors categorized as natural versus synthetic. Additionally, several sensory dimensions were identified as being related to the perception of naturalness in the olfactory domain, in particular the dimensions of intensity and pleasantness of odors. Finally, studies 3 and 4 evidenced that the identification of odors has a key influence in the perception of the naturalness of odors. Our studies have also highlighted an important inter-individual variability occurring in the perception of naturalness. Our results suggest that attitude toward naturalness may explain some of this variability, but further research is needed to clarify these results. Finally, in our studies, we also observed cultural variability in perceived naturalness of odors.

These results allow a better understanding of the notion of naturalness applied to olfaction. Further research will consolidate and extend these results. In particular, several perspectives seem relevant to us. First, the extension of this research to new cultural areas in order to study the perception of naturalness in cultures with different conceptions of the Human-Nature relationships. Second, diversifying the olfactory stimuli would allow us to deepen our results on the effect of odorants on naturalness perception, but also on the relationship between pleasantness and the naturalness by studying naturalness perception of unpleasant smells. Finally, further characterization of the effects of variables identified as related to the perception of naturalness is an interesting avenue in the continuity of our research, as for example for the effect of intensity on the perception of naturalness.

RESUME

De nos jours, l'intérêt que suscite la naturalité est croissant. Les produits naturels sont perçus comme supérieurs aux produits non naturels sur de nombreux aspects, tels que l'impact sur la santé ou l'environnement. Au-delà des considérations marketing, des études en neuropsychologie et en neurosciences ont montré la pertinence de la distinction naturel/manufacturé pour la cognition humaine.

Parmi les différentes façons d'étudier le caractère naturel, l'étude des marqueurs sensoriels du caractère naturel, et notamment les caractéristiques olfactives, semble être une voie fructueuse, bien que peu étudiée. En effet, du point de vue de l'industrie, répondre aux attentes des consommateurs concernant les caractéristiques sensorielles des produits étiquetés comme naturels est un enjeu fort. Du point de vue de la recherche, l'olfaction présente des particularités par rapport aux autres modalités sensorielles, l'étude du caractère naturel des odeurs pourrait donc fournir de nouveaux éléments pour mieux comprendre la perception de la naturalité. L'objectif de notre recherche était donc d'identifier les marqueurs sensoriels et cognitifs de la naturalité dans le domaine olfactif.

Dans notre recherche, nous avons dû faire face à trois difficultés majeures : la naturalité est un concept vague et polysémique, différents niveaux d'analyse de la perception des odeurs doivent être distingués et considérés pour étudier la perception olfactive, et la forte variabilité interindividuelle intervenant sur les deux éléments précédents.

Une revue de la littérature sur la notion de naturalité nous a permis de préciser le sens de cette notion. En effet, nous avons pu fournir une définition de travail selon laquelle la naturalité est caractérisée par une absence d'influence humaine. Ensuite, en étudiant les connaissances disponibles sur la perception olfactive, nous avons identifié trois niveaux pertinents pour étudier la perception olfactive des odeurs : les niveaux de la source physique, perceptif et cognitif. Dans notre recherche, nous avons cherché à déterminer les contributions respectives de ces trois niveaux à la perception du caractère naturel des odeurs. De plus, au cours de nos recherches, nous avons pris en compte la variabilité interindividuelle concernant la perception de la naturalité et les attitudes.

Pour répondre à cet objectif, nous avons mené quatre études. La première étude visait à développer une échelle attitudinale capable de mesurer la variabilité interindividuelle des attitudes envers la naturalité. L'objectif était également de tester dans quelle mesure cette

variabilité attitudinale pouvait expliquer une part de la variabilité dans la perception de la naturalité des odeurs (études 3 et 4). Les études 2 et 3 se sont intéressées aux facteurs sous-jacents à la perception olfactive de la naturalité, soit en étudiant les attentes des participants concernant les caractéristiques sensorielles des produits naturels (étude 2), soit en évaluant les propriétés des odeurs et leur relation avec la perception du caractère naturel (étude 3). Enfin, l'étude 4 s'est concentrée sur l'aspect crossmodal de la naturalité des odeurs en examinant le sens de la naturalité dans les modalités visuelle et l'olfactive.

Dans l'étude 3, les odeurs provenant d'odorants naturels ou synthétiques n'ont pas été distinguées en terme de naturalité. De plus, au cours de nos études, plusieurs dimensions sensorielles ont été identifiées comme étant liées à la perception du caractère naturel dans le domaine olfactif, en particulier les dimensions d'intensité et la valeur hédonique des odeurs. Enfin, les études 3 et 4 ont démontré que l'identification des odeurs a une influence sur la perception du caractère naturel des odeurs. Nos études ont également mis en évidence une importante variabilité interindividuelle dans la perception du caractère naturel des odeurs. Nos résultats suggèrent que l'attitude envers la naturalité peut expliquer une partie de cette variabilité, mais des recherches supplémentaires sont nécessaires pour clarifier ces résultats. Enfin, dans nos études, nous avons également observé une variabilité culturelle dans la perception de la naturalité des odeurs.

Ces résultats permettent de mieux appréhender la notion de naturalité appliquée à l'olfaction. Des recherches complémentaires permettront de consolider et d'étendre ces résultats. En particulier, plusieurs perspectives nous semblent pertinentes. Premièrement, l'extension de ces recherches à de nouvelles aires culturelles afin d'étudier la perception de la naturalité dans des cultures ayant des conceptions différentes des relations Homme-Nature. Ensuite, la diversification des stimuli olfactifs nous permettrait d'approfondir nos résultats sur l'effet des caractéristiques des odorants sur la perception de la naturalité, mais aussi sur la relation entre le caractère agréable et la naturalité perçue des odeurs, notamment en incluant des odeurs désagréables. Enfin, une caractérisation plus poussée des effets des variables identifiées comme étant liées à la perception de la naturalité est une piste intéressante dans la continuité de nos recherches, comme par exemple pour l'effet de l'intensité sur la perception de la naturalité.

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Table of Contents

ABSTRACT	3
RESUME	5
Acknowledgments/Remerciements	7
Table of Contents	9
Table of figures	10
Glossary	11
General Introduction	12
Part A – Theoretical Framework.....	16
Chapter 1- Naturalness definition	17
Chapter 2 - Olfactory perception and naturalness assessment	28
Part B – Empirical Research.....	46
Chapter 3- Assessment of attitude toward natural products	47
Study 1 – Product Naturalness Scale (PNS): development and validation of a new scale to measure attitudes toward naturalness for different categories of products	48
Chapter 4- Study of the factors modulating naturalness of smells.....	80
Study 2 – Olfactory attributes and colors associated with naturalness.....	81
Study 3- Perceptual and cognitive factors modulating the naturalness of smells.....	108
Chapter 5- Implicit measurement of naturalness of smells	136
Study 4- Congruent associations between natural images and natural odors	137
Part C – General Discussion.....	167
Chapter 6- Findings & Perspectives.....	168
References.....	181
Appendix.....	188
Appendix 1- On the contribution of the senses to food emotional experience	188

Table of figures

Figure 1: Representation of the dichotomy between natural kinds and artifacts	22
Figure 2: Representation of naturalness as a continuous gradient	25
Figure 3: Nasal epithelium structure	30
Figure 4: OSN projection on glomeruli.....	31
Figure 5: Primary (yellow) and secondary (blue) olfactory cortex	32
Figure 6: Perception of smells' naturalness is shaped by the naturalness of the physical source	34
Figure 7: Perception of smells' naturalness is shaped by the naturalness of the physical source and the sensory features of the smell	38
Figure 8: The three levels of analysis of smells naturalness perception	44

Glossary

Artifact: A human-made entity

GMO: Genetically Modified Organism

HP: Household Product

Identified source: The world entity associated to a smell through identification process

Natural kind: A naturally occurring entity

PCP: Personal Care Product

Physical source: The physical entity emitting a smell

General Introduction

The human consideration for nature, and the value they place on it, has fluctuated over the centuries and across cultures. In western cultures influenced by Christianity, nature has long been considered a demonic and bestial space (Descola, 2005). The natural state of human beings was seen as a primitive, disgusting, animal, and brief state, where “*Homo homini lupus est*” (“Man is wolf to man”, Hobbes, 1651). Subsequently, the scientific advances of the Enlightenment and then the Industrial Revolution endorsed the view of nature as a resource made available to human needs (Worster, 1994).

However, a romantic view of nature, in which nature is admired and respected, also developed in response to modernization (Worster, 1994). In the early 20th century, as a reaction to urban life and the development of agriculture, the question of the need for contact with and protection of nature emerged (Vogt, 2007). Wilson and Kellert (1995) even suggested with their biophilia hypothesis that contact with nature would be a human need. Their hypothesis was based on the observation of an "innate tendency to focus on life and life-like processes" (Kellert & Wilson, 1995, p.1). In addition, a growing number of scientific publications have examined the effect of contact with nature on human well-being, and the results suggest that regular contact with nature improves well-being (Bratman et al., 2012; Pirchio et al., 2021; Taylor et al., 2018).

Therefore, the attitude of humans toward nature and natural entities, i.e. the evaluation that humans make of these elements (Albarracin & Shavitt, 2018), has evolved over time. From a negative attitude toward nature several centuries ago, there is now a growing interest in naturalness (Descola, 2005; Vogt, 2007; Worster, 1994). This change in attitude has also been reflected in consumer habits, with a growing demand for organic and natural products, especially food (Schösler et al., 2013). Although the transformation of food has long been considered an improvement for human nutrition and food safety, the impact on health and the environment of certain chemicals used in agriculture led to a mistrust of these products. At the same time, the wariness of food additives also increased (Schösler et al., 2013). In this context, there is nowadays a growing demand for natural products.

In recent years, industry and academic research have thus sought to understand consumer motivations and expectations for natural products. A first observation was that the demand for natural products trend is widespread around the world. Studies conducted all around the world,

such as in Japan, the United States of America, France, or Poland on consumers' perception of natural food found that naturalness features among the most prominent factors explaining food choice (Román et al., 2017). However, although most of the consumers have a positive evaluation of naturalness, these studies also reported interindividual variability in the attitude toward naturalness. Demographic factors, such as gender and age, as well as other psychological traits, such as attitude toward chemicals, novel technologies or health interest, have been identified as influencing attitude toward naturalness (Román et al., 2017).

Naturalness appears nowadays as a positive food attribute, influencing its perceived quality (Rozin et al., 2004). Natural foods are expected to be healthier, more respectful of the environment, tastier, and fresher than their non-natural counterparts (Román et al., 2017). Moreover, preferences for "natural" exceed instrumental motivations, defined as material or functional superiority in healthiness, effectiveness, sensory qualities, or purity. This preference is also based on ideational motivations, i.e. "the desirability of natural per se (for moral or ideational/aesthetic reasons)" rather than physical attributes (Rozin et al., 2004, p.152). Rozin and his colleagues suggested that instrumental beliefs are less important than ideational beliefs (Rozin et al., 2004). Indeed, in Rozin's study (2004), 57% of the participants preferred natural food even when it was specified that natural food, like an apple, was equally tasty, healthy, or chemically identical, to the same commercial food (Rozin et al., 2004). For the authors, these results refer to the belief in the benevolence of nature. Natural entities would be inherently better than human-made ones (Rozin et al., 2004).

In order to meet consumers' expectations of natural products, research has investigated the factors modulating the perception of the naturalness of the object. Results showed that several factors affect naturalness perception, such as the type of production process or the nature of the ingredients (Evans et al., 2010; Rozin, 2005). Moreover, some studies also found that sensory factors also modulated naturalness perception, such as visual (Deliza et al., 2003), tactile (Labbe et al., 2013), or gustatory characteristics of products (King & Duineveld, 1998). However, only two studies have explored naturalness for odors, and these studies focused on the relationship between naturalness and pleasantness ratings rather than on sensory markers of smells' naturalness. The body of research on the sensory factors modulating naturalness is thus still limited. Furthermore, because naturalness has been studied primarily with semantic and to a lesser extent with visual stimuli, it is difficult to characterize the naturalness of odors, and thus to study naturalness perception with olfactory stimuli.

The scarce evidence about the olfactory markers of naturalness is a matter of concern for the manufacturers of flavors and fragrances. Indeed, the mismatch between naturalness expectations and the actual perception of naturalness resulting from the integration of the semantic and sensory properties of the object can lead to a rejection of the product. To prevent such a risk, a thorough study of markers of odor naturalness is needed. In addition, a better understanding of the perception of the naturalness of smells would be of interest for a variety of reasons. For example, because odors share a special connection with emotions (Ehrlichman & Bastone, 1992), olfaction might thus be a good modality to explore the link between well-being and naturalness. Furthermore, olfaction has specificities compared to the visual domain, such as the fact that identification is more ambiguous for odors than for images. Studying naturalness with the olfactory modality could therefore shed light on factors that modulate naturalness and that have not been identified using semantic or visual stimuli.

However, a prerequisite for addressing the question of the naturalness of smells is to deal with three main problems: the polysemy of naturalness, the ambiguity of smell, and interindividual variability in the definition of naturalness and olfactory perception. The first difficulty is that the term natural is polysemous and vague. Indeed, the term natural encompasses different meanings, referring for example to innate (having a natural gift for playing the piano), to familiarity (it is natural to say hello when you meet someone), or to the absence of human influence (an object is natural because it has not been modified by humans) (Siipi, 2008). The latter meaning, since it is particularly related to the growing demand for natural products and attitude towards nature, is of particular interest. However, this meaning is also vague, as the exact boundary between natural and non-natural entities is difficult to establish. Before studying the naturalness of odors, it was therefore necessary to clarify the concept of naturalness. We will develop further this issue of polysemy and the difficult definition of naturalness in Chapter 1.

A second problem is that different level of analysis can be considered to evaluate the naturalness of smells. This issue is developed in Chapter 2. Indeed, "smell" can refer to different types of objects. The odor can refer to the mixture of molecules emitted by a physical object and responsible for an odor (e.g. "we used the cis-3-hexanol odor"). Therefore, the level of the odorant appears relevant for assessing naturalness of smells, as difference of naturalness of the odorant could result in difference of perception of naturalness of the smell. However, if we consider the perceptual level, odors refer to a subjective perception, for example in the sentence

"I smell a pleasant and green odor". Perceptual features of the smell might thus be related to naturalness perception. Furthermore, olfaction is also a sensory modality that is very prone to cognitive modulation, and the cognitive level must also be taken into account. For example, one can use the term "smell" to refer to the identified source of the smell, such as "it is the smell of cut grass". Therefore, which level should be considered as the right locus of naturalness judgments or perceptions? In our research, we sought to understand how these three levels modulate the perceptual experience of the naturalness of odors.

Finally, the last problem concerns inter-individual variability. Indeed, variability occurs at the level of the definition of naturalness, since there is no consensus on the right definition of naturalness. In addition, it is also one of the characteristics of olfactory perception since odors can be perceived differently from one individual to another (Mantel et al., 2021). We therefore ensured that this element was considered in our research.

From an empirical perspective, these issues of defining naturalness, the ambiguity of odors and interindividual variability have been investigated through different studies (Part B). In our research, we have diversified our experimental methods, each providing different information for understanding the perception of the naturalness of odors. First, we developed an attitudinal scale measuring variability in the attitudes toward natural products, for three product categories: food, personal care products, and household products (Chapter 3, Study 1). The purpose of this scale was to better delineate the concept of naturalness and to investigate the effect of attitudinal variability on naturalness perception (Chapter 4, Study 3 and Chapter 5, Study 4). We also explored the markers of naturalness used to assess the naturalness of odors, either through expectations about the sensory features of natural products and smells (Chapter 4, Study 2) or through the study of perceptual and cognitive factors modulating the perception of smells' naturalness (Chapter 4, Study 3). Finally, we explored the cross-modal aspect of the meaning of naturalness using implicit measures (Chapter 5, Study 4). Specifically, we investigated whether the meaning of naturalness is shared between visual and olfactory modalities. Throughout our research, we also investigated cultural variability in the definition and perception of the naturalness of odors, comparing the results between French and American samples. In the 6th chapter, we discuss the contributions of the different experimental phases to the understanding of odor naturalness markers, as well as the limits and perspectives of our work.

Part A – Theoretical Framework

Chapter 1- Naturalness definition

1. The polysemy of naturalness

1.1. Naturalness, an undefined and non-consensual term

The only consensus on the definition of naturalness might be that there is none. The terms "natural" and "naturalness" are used with a wide range of different meanings, depending on the field (e.g. naturalness in ecology has a different meaning from that applied to food), or on the authors' own interpretation of these terms. Reviewing research conducted about attitudes toward natural food, Roman and colleagues (2017) investigated the way naturalness has been defined and measured in the 72 studies they identified. Their first result of interest is that there is no widely accepted definition, each author providing its own. For example, Onyango and colleagues (2006, p.65) defined natural food as "the foods containing neither preservatives nor artificial colorings" while for Bäckstrom et al. (2004, p.81) natural food refers to "organically grown food, signaling the importance of nature." In addition, there is no definition in official organizations. The US Department of Agriculture addressed this issue in the 1990s, but no definition was established at that time (Sandin, 2017). There is also no official definition of naturalness or natural products provided by the European Union.

This lack of definition might explain some controversies about the naturalness of certain entities and their properties. A good example is that of genetically modified organisms (GMOs) which are controversial entities. Are GMOs more natural than traditional farmed species? Inter-individual variability in the definition of naturalness might explain that different authors brought different responses to this question (Lepiller, 2016; Scott & Rozin, 2020). As some authors argued, the genetics of domesticated species, such as strawberries, have been more modified than those of GMO corn (Scott & Rozin, 2020; Siegrist et al., 2016). Indeed, in the former case, many of the strawberry's genes have been modified by human selection for centuries, whereas only one modified gene has been introduced in the case of the GMO. Another view of GMOs' naturalness is linked to the relation between naturalness and spontaneity (Lepiller, 2016). Indeed, in one case, humans have selected the changes that occur "naturally", i.e. spontaneously (domestication), in the other case, they have created this change by deliberately introducing new genes into the genome of the crops. Considering these different meanings of naturalness could explain the inter-individual differences in the perception of entities' naturalness. Moreover, as Helena Siipi highlighted (2013), the properties of natural entities depend on the definition chosen. For example, the relation between healthiness and

naturalness varies according to the definition of naturalness, as natural entities are inherently healthier than non-natural counterparts in some definitions, while the two dimensions are unrelated in other definitions.

Furthermore, this diversity in the definition of naturalness could also hinder academic research on naturalness. Indeed, as Romàn and colleagues (2017) pointed out, measures of attitude toward naturalness differ among authors. For example, biological dimension (e.g. Bäckström et al., 2004), local aspect (e.g. Renner et al., 2012), or freshness (e.g. Hemmerling et al., 2016), are included in the range of the definition of naturalness by some authors but not by all. These differences raise the issue of generalization and comparison of results across these studies. Are they measuring the same construct?

There is thus a need to provide a clear and consensual definition of naturalness. Several authors have tackled this complex problem of defining naturalness. However, they have encountered two main resistances: naturalness is a polysemous and vague term.

1.2. Overview of naturalness meanings

Natural and naturalness terms are polysemous. The French national center of textual and lexical resources counts no less than 22 different meanings for the word "natural"! Some of them are very close, some others are applied to very different entities or contexts. Natural can for example refer to innate dimension, e.g. someone with a "natural gift" to design Implicit Association Tasks, or to spontaneity, such as "I am very natural with my friend". Therefore, it is important to have an overview of the meanings of naturalness as it can underpin inter-individual variability in the perception of naturalness.

Probably the most common meaning of the term "natural" is: that has not been modified by humans. Naturalness is therefore seen as an absence of human influence (Siipi, 2008), and each transformation induced by human contact decreases the naturalness of the object (Scott & Rozin, 2020). This meaning is widely used in consumer studies on naturalness, the natural products being the less transformed ones (Evans et al., 2010; Rozin, 2005; Rumiati & Foroni, 2016). Studies on naturalness and well-being also relied on this meaning of naturalness, the contact with nature being with living and non-transformed entities (Bratman et al., 2012; Pirchio et al., 2021; Taylor et al., 2018). However, paradoxically, the term "natural" is sometimes applied to humans, although this may seem contradictory to the meaning of natural as the absence of human influence. For example, some humans have "natural" abilities, such as

the natural ability to play piano, or some human behaviors can be considered "natural" or "unnatural".

As Helena Siipi (2008, 2013) points out, another sense of naturalness relates to familiarity. Customary entities are considered natural, such as cow's milk cheese, while foreign, new, or odd entities are not natural, such as plant milk cheese. Following this link to familiarity, naturalness has been linked to tradition and authenticity. Products processed by traditional methods, e.g. making wine from grapes, are perceived as more natural than those processed by new processes, e.g. deep frying of food (Etale & Siegrist, 2021). Authenticity, in the sense of being real and true to an essence, was contrasted with artificial or synthetic (Siipi, 2013). Furthermore, as the author highlights, familiarity-related naturalness is necessarily relational. It depends on the familiarity between the two entities. For example, exotic species are not necessarily unnatural entities in absolute terms, but it is not natural to see a lion in Paris. Species have a "natural environment", in the sense of the environment where they are commonly found, and it is not natural to see them in a different environment. Naturalness related to familiarity also conditioned naturalness of human behaviors, the common behaviors been seen as the natural ones (e.g. it is natural to brush your teeth before sleeping). The qualification comes from the naturalization of familiar behaviors (Lepiller, 2016). The natural is then brought closer to "normal", in the sense of a statistical concept. What is natural is what is common and usual (Siipi, 2008).

Furthermore, to add more complexity, naturalness applies to different types of concepts. It can apply to physical entities (e.g., a natural vs. an artificial flower), behaviors (e.g., it is natural to fly in front of a bear), or even events (e.g., "natural disasters" are sometimes considered artificial, Abramovitz & Starke, 2001), and spaces (e.g., a natural vs. an artificial lake). Moreover, each language may have its own meanings for the term natural, which leads to a very wide range of possibilities.

To help clarifying naturalness definition, Helena Siipi (2008) has proposed a classification of the meanings of naturalness with three main forms and many sub-forms:

- History-based (un)naturalness: naturalness is then assessed based on the type of modifications it has undergone, regardless of the properties of the final entities. For example, Paul Rozin and his colleagues found that the addition of artificial ingredients that are then removed in the subsequent manufacturing process still decreases the

perceived naturalness of the final product. As the author points out, history is more important than content (Rozin, 2005).

- Property-based (un)naturalness: This definition of naturalness is based on the properties of the final entities. For example, a restored ecosystem may be natural because it has the same properties as the previous natural ecosystem. Nevertheless, it is in contradiction with history-based unnaturalness, according to which a restored ecosystem is unnatural because it has been recreated by humans.
- Relation between entities: This form of naturalness is strongly related to familiarity. For example, hay is a natural food for horses but not natural for humans. An environment is (un)natural for a given species, however, it is neither the species nor the environment that are (un)natural, but the relationship between the two.

Considering the range of possible definitions of naturalness, it is thus necessary to narrow the meaning we will refer to when using the terms natural and naturalness. As Sydney Scott and Paul Rozin (2020) pointed out for the food domain, the lay definition of naturalness relies on the perception of human influence, as natural entities are those untouched by humans. Moreover, this lay definition is supported by research in neuropsychology and neurosciences which brought evidence of the relevance of the naturalness dimension as an absence of human influence.

1.3. Evidence for differential cognitive and neural processing of natural kinds and artifacts

Research in neurosciences and neuropsychology highlighted differential cognitive and neural processing of natural kinds (the naturally occurring object) vs artifacts (human-made objects). Raffaella Rumiati and Francesco Foroni (2016) investigated how food is represented in the brain by reviewing how brain-damaged patients recognize natural and manufactured objects. Different pathologies, such as Alzheimer, herpes simplex encephalitis, or brain damages due to accidents result in agnosia (i.e. disability to recognize or name objects). Interestingly, cases of category-specific agnosia were reported. For example, Warrington and Shallice (1984) reported the cases of patients unable to recognize natural entities (including animals, fruit, vegetables, plants, and some transformed food), but with intact ability to recognize non-living objects (see Rumiati & Foroni, 2016 for further examples). Although fewer in number, some cases of inability to recognize human-made objects have also been reported, while recognition of natural entities was spared (Warrington & McCarthy, 1987). One of the hypotheses put forward to explain these category-specific impairments relies on the existence of two domain-specific

semantic subsystems. The domain of living things would be represented in the sub-system processing the sensory properties preferentially such as shape and texture, while the processing of non-living entities would occur in the subsystem representing functional properties preferentially (e.g. function and uses) of objects (see Rumiait & Foroni, 2016 for further discussion on this hypothesis and other explanations for category-specific impairment).

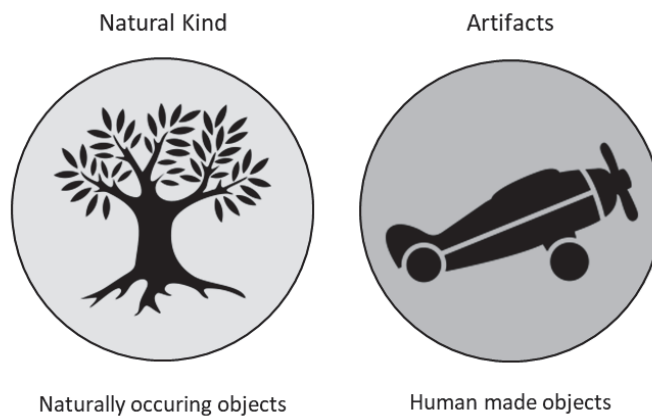
Moreover, results from functional neuroimaging studies also suggested differential neural patterns of activation in the processing of natural and manufactured objects. In a meta-analysis conducted in 2001, Jane E. Joseph investigated the cortical organization of semantic knowledge. Results revealed differential patterns of brain activation in response to the presentation of images of natural objects versus manufactured objects, especially in the fusiform gyrus and ventral temporal cortices (Joseph, 2001).

The above elements thus suggest differential cognitive and neural basis for the processing of natural entities and artifacts, bringing evidence of the psychological relevance of the naturalness dimension. In the rest of our research, we have thus focused on naturalness as an "absence of human influence". Nevertheless, this meaning of naturalness remains vague, as the degree of human influence distinguishing natural from artificial entities is still a matter of debate (Borghini, 2014; Sandin, 2017; Siipi, 2008).

2. The vagueness of naturalness

2.1. The difficult cutoff between natural kinds and artifacts

Two categories are used to divide the entities according to their naturalness (Figure 1), but the exact cutoff between these categories is difficult to ascertain. On one side are the natural kinds, the naturally occurring objects, and on the other side are the artifacts, which are human-made objects (Gelman, 1988). Artifacts are designed by humans to fulfill a purpose, to meet specific humans need. They are categorized based on their functions or purpose even though they may eventually serve other functions, a frying pan being a frying pan because it is used to cook food. On the other side, natural kinds are natural because they occur naturally. However, the categorization of many entities in one or the other category is ambiguous. Are domesticated species natural kinds or living artifacts? Domesticated species, such as cats, have evolved with humans for centuries now, and their genetics have thus been strongly transformed by human contact. Moreover, are they as artificial as plastic chairs? Different authors suggested different cut-off points to distinguish natural kinds from artifacts.



*Figure 1: Representation of the dichotomy between natural kinds and artifacts
(tree and plane illustration from Evi1000 & Vectors Market from the nounproject.com)*

A first view would be to consider as unnatural all objects that have been modified by human influence, directly or indirectly. However, our era is shaped by global warming, the decline of biodiversity and large-scale plastic pollution. Under these conditions, are there still entities that have not yet been modified by human influence? Endorsing this view, some authors have suggested that there are no natural entities anymore (McKibben, 1990).

Other authors suggested that this is not the fact that entities have been influenced by humans, but the fact that humans did it intentionally that makes the difference between natural entities and artifacts. In this view, naturalness is closely related to wilderness. What makes a mushroom natural and wild is that, even if it has been modified by human influence, it grew up spontaneously (Sandin, 2017). Nobody planted it with the purpose of eating it. This criterion might introduce a distinction between wild and domesticated species. Indeed, in the first case, species evolved following the selection process and evolutionary principles, while in the former case the process of selection is driven by human intention. Mountains and recreational areas are other examples. Hikers might, by walking always on the same path, create visible trails. These paths are, sometimes but not always, created unintentionally. Besides the visible influence of humans, the absence of human intention in managing space makes it a wild space evolving unpredictably (Sandin, 2017). The function would then be the characteristic that differentiates natural kinds from artifacts: artifacts are intentionally designed with the purpose of fulfilling a function, while natural entities evolve spontaneously without any purpose (Katz, 1993).

However, in the food domain, natural have also been applied to domesticated species, the cut-off being between raw and processed food. Rumiati and colleagues (2016) applied for example the term "natural" to fruits and vegetables, while the opposite, the manufactured food,

“underwent some kind of organoleptic transformation” (Rumiati & Foroni, 2016, p.1044). From a different perspective, Paul Rozin and colleagues (2004) have defined natural food as “one that had not been changed in any significant way by contact with humans. It could have been picked or transported, but it was chemically identical to the same item in its natural place”. The authors have opposed natural food to processed food, defined as “one that had been grown with fertilizers or pesticides and that might contain additives or preservatives to enhance its taste” (Rozin et al., 2004, p. 148). Moreover, the ambiguity remains about the kind of food entering the natural category. For example, are domesticated fruits "chemically identical to the same item in its natural place"? On the other hand, do washed and cut fruits undergo organoleptic transformations? An apple pie might contain no additives or preservatives, but at the same time underwent obvious organoleptic transformations.

To explain this apparent contradiction, some authors have made the distinction between whole natural food and compound natural food (Borghini, 2014). For the author, whole food is natural if it has not been subject to any modification, except those that are suitable to make it edible. This is for example the case of natural dairy that has been manufactured with milk alone and following fermentation process with traditional bacteria. On the other side, compound natural food is natural because all the ingredients are natural. Thus, while the previous example of apple pie cannot be a whole natural food because it has obviously been subject to modification, it can still enter the category of compound natural food if all its ingredients are natural. This definition may be extended to other categories of products, natural compound products being those containing only natural ingredients. However, the use of the term "natural" for products containing only natural ingredients only transfers the issue of the definition of "natural" to the ingredient level.

The question of the definition of natural ingredients remains quite the same as for the whole object: is it an absence of any form of human influence, an absence of human purpose in the modification of the ingredient, or a modification that does not alter its organoleptic or chemical properties? In the domain of ingredients, natural ingredients are sometimes opposed to synthetic ones (Borghini, 2014). The latter is obtained through a process of chemical synthesis, making them unnatural, such as synthetic vanillin, while the former is extracted from natural objects, like vanilla extracted from vanilla beans. The issue of spontaneity might underpin this distinction. As Andrea Borghini (2014) highlighted, a golden apple may be the result of human effort, but in a way, it occurs spontaneously while chemical synthesis is very controlled and

does not happen spontaneously. The kind of process used to obtain the ingredients may also partly determine their naturalness. Indeed, some processes are seen as natural because occurring spontaneously in nature, such as some fermentations. Thus, some yogurts will be considered natural because obtained from the fermentation of bacteria, while others containing additives and artificial flavorings are not natural because they contain synthetic ingredients.

The exact cut-off between natural kind and artifacts remains thus debatable. The criteria of the will and purpose of human action causing the modification or the spontaneity with which the alterations occur necessarily divide objects into two categories. However, considering the other criteria used to set this distinction, it appears that they vary in terms of the degree of human influence set as the cut-off and the kind of human influence. Indeed, for some authors any kind of human influence makes objects unnatural, while others considered the chemical alteration resulting from human contact. Hence, considering the example of domesticated species and food that are ambiguous as to which category they belong to, some authors have suggested that naturalness may be best represented as a continuum (Gelman, 1988; Lepiller, 2016; McKibben, 1990; Siipi, 2008).

2.2. Naturalness as a continuous gradient

Naturalness might be represented as a continuous gradient, in which naturalness varies from very natural to not at all natural (Figure 2). Moreover, the degree of human influence, as it decreases the naturalness of entities, might define the place of an object on this continuum (Siipi, 2008). The use of a continuum has several advantages. First of all, it avoids the question of defining a cut-off point between two categories, which is subjective and varies according to the authors. Secondly, it enables the comparison of naturalness between objects. For example, a mountain on which no human has ever put a foot might be more natural than a mountain in a National Park on which thousands of hikers hike every year. Moreover, this mountain is also more natural than a countryside shaped by agriculture, which is still more natural than a city with buildings everywhere. In addition, this representation allows for the measurement of naturalness using a continuous scale rather than asking participants to categorize entities, which can provide a more fine-grained measure of perceived naturalness.

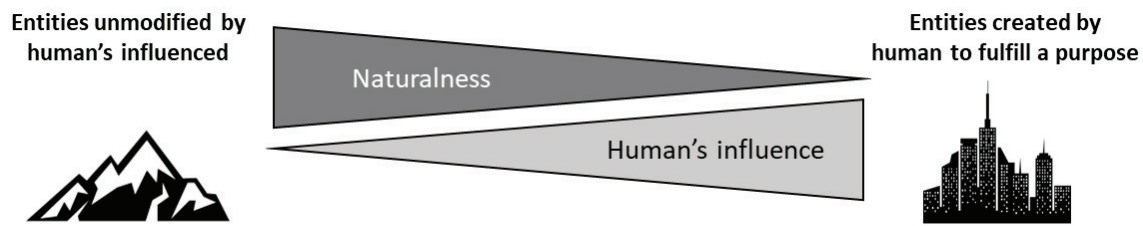


Figure 2: Representation of naturalness as a continuous gradient
(Mountain and city from the nounproject.com)

However, as Helena Siipi put forward, an issue remains about the dimension used to set the place of objects along the continuum. This could first be the amount of effort and time that humans spend to modify an entity (thus based on the history of the entity). Or it could be based on the impact of human influence on the entity's properties (thus based on the entity's properties rather than the entity's history) (Siipi, 2008). GMOs would be more artificial than domesticated species following the first approach, while the opposite would be true according to the second approach. Studying the factors modulating the perception of naturalness along this continuum could help determine which of these two possibilities is more explanatory.

2.3. The factors modulating naturalness perception

Several factors affecting naturalness have been identified, emphasizing that not all human actions affect naturalness to the same extent.

The largest body of research on factors affecting naturalness perception focused on the production process and nature of ingredients used. To further analyze the notion of naturalness, Paul Rozin and his colleagues (2005) studied which human actions decreased the most the naturalness of a natural kind. Beginning with an entity that most Americans would have thought of as very natural (i.e. spring water or peanuts raised without any fertilizers or pesticides), they determined the denaturalizing effect of a variety of transformations of that natural object (grinding; adding fat; adding synthesized and purified minerals, etc). In addition, they asked participants to rate the naturalness of 59 items on a scale ranging from 100 being completely natural, to 0, which were completely unnatural. Their results suggested that, firstly, the principle of contagion, i.e. the permanent transfer of properties from one object to another after a brief contact (Rozin et al., 1986), accounted for many aspects of the reduction of naturalness. Indeed, contact with unnatural entities (e.g. use of fertilizer or pesticides) reduces naturalness evaluation, even if this ingredient was removed later in the production process. This contagion depended on the naturalness of the additive, as adding synthesized minerals alters the

naturalness of water more than adding natural minerals. For the process of production, Paul Rozin and colleagues (2005) observed that chemical transformations (e.g. adding fat) reduced naturalness much more than physical transformations did (e.g. grinding). In line with Rozin's study, Evans and colleagues (2010) suggested that the more the food was processed the less it was perceived as natural. Abouab and Gomez also showed that the production mode (hand-made vs. machine-made) also played a role in the naturalness evaluation, suggesting that higher perceived human contact during the process preserved, or at least damaged less food naturalness than contact with machines (Abouab & Gomez, 2015).

Besides the level of transformation of products and type of ingredients, several factors identified in the literature as modulating naturalness may be based on a different meaning of naturalness than an absence of human influence. The effect of the name of the ingredients for example points out the effect of familiarity on the perception of naturalness. Indeed, several authors suggested that E-numbers or chemical names are evaluated as less natural than their equivalents with common names because these names are also less familiar to participants (Evans et al., 2010; Murley & Chambers, 2019, 2019). Furthermore, Etale and colleagues (2021) found that naturalness is also related to the perception of tradition, as traditional processes (e.g. making of wine from grapes) alter less naturalness than new and more technological processes (e.g. freeze drying granulated coffee). In addition, they found that the scale of the production also affects naturalness perception, with the products produced at a smaller scale being perceived as more natural than those products at an industrial scale.

Interestingly, some studies found a modulation of naturalness perception based on sensory features of the products or their packaging. For example, the color of the package (orange vs white) influenced the expected freshness and naturalness of fruit juice (Deliza et al., 2003). In their study, 125 participants rated the sweetness, pureness, sharpness, refreshing, freshness, naturalness, and also the expected liking of 24 pictures showing a bottle of passion-fruit juice. The results showed that the white bottle and the bottle providing more information were perceived as more natural, purer, fresher, and more appreciated. The material (cardboard or fabrics for example) used for the packaging has also an effect on the perceived naturalness of the product. In a study conducted in 2013, Labbe et al. showed that the visual, tactile and auditory characteristics of a material can influence the expected naturalness of a dehydrated soup. They observed a positive correlation between roughness, suppleness, and expected naturalness, and a negative correlation between image intensity and expected naturalness

(Labbe et al., 2013). Although sparse, these results suggest modulation of naturalness perception by sensory dimensions.

In summary, factors identified as modulating the perception of naturalness mainly rely on the type of process applied to the product and the nature of the ingredients used. Moreover, investigations of contextual factors affecting naturalness pointed out that sensory features, such as tactile properties or colors of packaging, influence naturalness perception.

3. Conclusion

Naturalness is a vague and polysemous concept. Although there is no right or wrong definition, a choice has thus to be made about to clarify the meaning of naturalness we use in our research. The meaning of naturalness as "absence of human influence" is particularly interesting because it is related to the demand for natural products. More importantly, studies in neuropsychology and neurobiology provide evidence of the relevance of this dimension. However, naturalness can be represented as a dichotomy or a continuous gradient. The continuum representation has several advantages, including avoiding the issue of the exact boundary between natural types and artifacts and allowing the comparison of objects to each other. This representation is more consistent with the study of factors modulating perceived naturalness, which investigates how certain factors modulate the level of perceived naturalness with continuous scales.

Among these factors, some factors related to the sensory properties of objects have been identified. Nevertheless, factors related to the olfactory properties of objects remain understudied. This lack of research on this subject is unfortunate for several reasons. First, a poor understanding of the naturalness of odors may lead to a mismatch between the evaluation of the naturalness of an object and the sensory experience of the naturalness of that object. Furthermore, a better understanding of the basis of the perception of odors' naturalness could also open up certain fields of research to the use of olfactory stimuli. Finally, olfactory specificities could also shed light on factors that modulate naturalness and that would not have been identified yet due to the exclusive use of semantic or visual stimuli.

Chapter 2 - Olfactory perception and naturalness assessment

Who has never appreciated a smell because it evokes cut grass, undergrowth or rain after a warm day? On the contrary, who has never experienced a candy whose flavor is so artificial that it probably does not exist in its natural state? It seems that we are able to judge about the naturalness of smells. Naturalness would even be one of the dimensions used to describe smells. Marylou Mantel (2021) found for example that for some smells, participants spontaneously refer to the naturalness dimension to describe their olfactory experience.

However, in the academic literature, the term “natural smells” has been applied to different kinds of odorants and for different purposes. For example, the term "natural olfactory stimuli" has been used to refer to freshly blended and mashed fruits, such as bananas or strawberries (Johnson et al., 2010; Ruebenbauer et al., 2008), or odorants coming from extraction process (Herz, 2003), and has been opposed to synthetic monomolecular odorants (Herz, 2003; Ruebenbauer et al., 2008). In addition, the term "natural smell" has also been applied to the use of real objects as stimuli, even if they are not natural entities, such as baby powder, peanut butter, or potato chips, as opposed to synthetic odorants (Cain & Krause, 1979). In this last example, the term "natural" is closer to the meaning of authenticity and realness, than to the meaning of the absence of human influence. Following this meaning of realness, "natural odor" has also been employed for body odor in absence of deodorant or perfume (Gaby & Zayas, 2017). Essential oils have also been considered natural odorants because the molecules are extracted from a real object and are only slightly transformed (Apaolaza et al., 2014; Lehrner et al., 2000). The term "natural" has thus been applied to different types of odorants, and the criteria that make an odor natural or artificial remain ambiguous.

One of the difficulties of providing a definition of what natural smells are lies in the ambiguity of the object the term "smell" refers. Seemingly simple, it is far from easy to provide an answer to what a smell is. As Ann-Sophie Barwich highlighted, "Ask six people working in olfaction what odors are, and you get six—if not more—answers" (Barwich, 2020, p.80). Thus, several elements might be considered when assessing the naturalness of smells. As we will first see, smells are very related to their physical source, i.e. the object emitting the odorant molecules. Therefore, perception of naturalness of smell might differ between natural and artificial physical sources. Moreover, most of the definitions of "natural smell" used in previous research and cited above relied on the naturalness of the odorant (e.g. essential oil or real object as opposed to synthetic odorants) to evaluate the naturalness of smells. However, as we will

expose in a second part, smells are related yet distinct from their physical source. Smells are subjective sensations resulting from the interpretation of a chemical message. Therefore, the perceptual level should also be considered, as naturalness may be modulated by perceptual features of the smell. However, as we will last discuss, the perception of smells is also influenced by cognitive factors. Among them, the semantic information provided by smells' names is of particular interest. Thus, consideration of the cognitive level may reveal the influence of the semantic labels associated with smells on perceived naturalness.

1. The physical source and the perception of smells

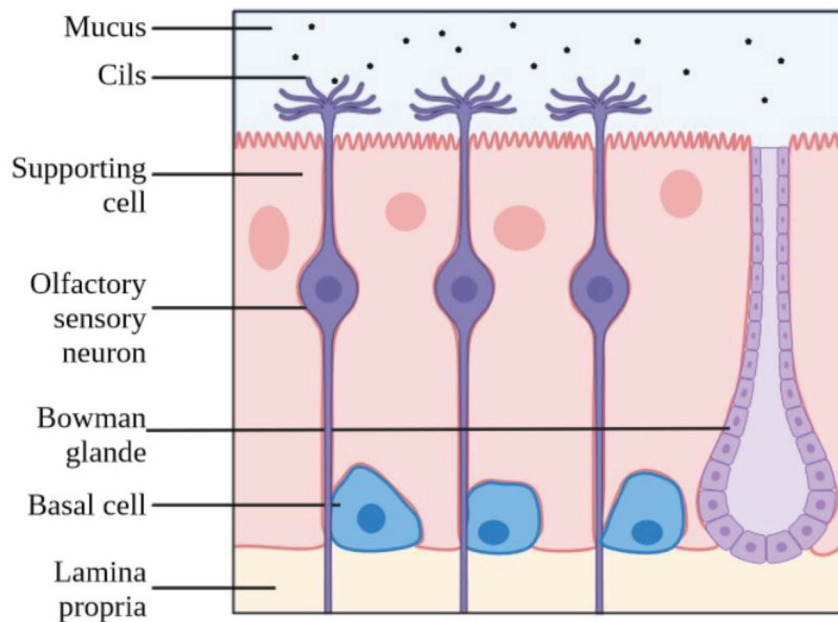
1.1. Odor as a signal

A smell is a signal. It is a cue indicating that an odorous entity is, or has been, in the surrounding environment. A smell can alert us of danger, as the smell of smoke can signal a fire or the smell of spoiled food that the dinner is not edible anymore. It can also indicate the presence of edible food, and the smell of palatable food can even induce salivation (McCrickerd & Forde, 2016)! Smells provide us with essential information about the entities that surround us and about ourselves, and as such, they have several important functions in our daily lives. Moreover, this function of signal induces a special link between the smell and its physical source. Indeed, more than an object in itself, the smell as a signal is a unimodal representation of its source, allowing us to know the presence and the nature of the source. In this sense, smells have a representational power, which means that the perception of smells are associated with mental images relating to features in the world (Barwich, 2020). This connection between smell and its source also comes from the neurobiological organization of the sense of smell.

1.2. Neurobiology of smells

An odor comes from an entity that emits volatile molecules. These molecules are volatiles, which means that they can spread through the air. Spreading into the air, they enter the nasal cavity and then reach the olfactory epithelium, which is a tissue consisting of mainly three types of cells: the olfactory sensory neurons (ONS), the supporting cells and the basal cells (Figure 3). The ONS express the genes coding for the olfactory receptors (Buck & Axel, 1991). The binding of odorant molecules to these receptors leads to the activation of specific G proteins, and thus induces a cascade of intracellular reactions resulting in the generation of an action potential, it is the transduction (for further description of the cascade of events in cell see DeMaria & Ngai, 2010). At the time of the binding of molecules to the receptors, the chemical

message carried by the mixture of molecules emitted by the source entity is thus converted into a nervous message transmitted by the neurons.



*Figure 3: Nasal epithelium structure
(Figure created by the author on BioRender.com)*

Through the olfactory nerve, olfactory sensory neurons project their axons to a forebrain region, the olfactory bulb (OB), which constitutes the first relay in the neuronal pathway of olfactory perception. In the olfactory bulb, the information passes through the synapse between the incoming axons of OSN to the dendrites of olfactory bulb cells. This relay occurs in specific structures of the OB, the glomeruli, which are spherical knots of neuropil. Interestingly, the OSNs express only one of the 400 types of olfactory receptors (OR) (Chess et al., 1994; Ressler et al., 1993; Vassar et al., 1993), and the ORs are able to be activated by several specific odorants (Malnic et al., 1999). Moreover, all the neurons expressing a particular OR converge to the same specific glomerulus (Mombaerts et al., 1996; Ressler et al., 1993; Vassar et al., 1993) (figure 4). Therefore, a specific pattern of OR activation in the nasal epithelium leads to a specific pattern of glomeruli activation in the olfactory bulb (Krautwurst, 2008; Mori, 1999). The specificities of OR expression, odorant-receptor binding, and OR-glomerulus convergence underlie the great human ability to discriminate a wide range of different types of odorants (Malnic et al., 1999; Krautwurst, 2008).

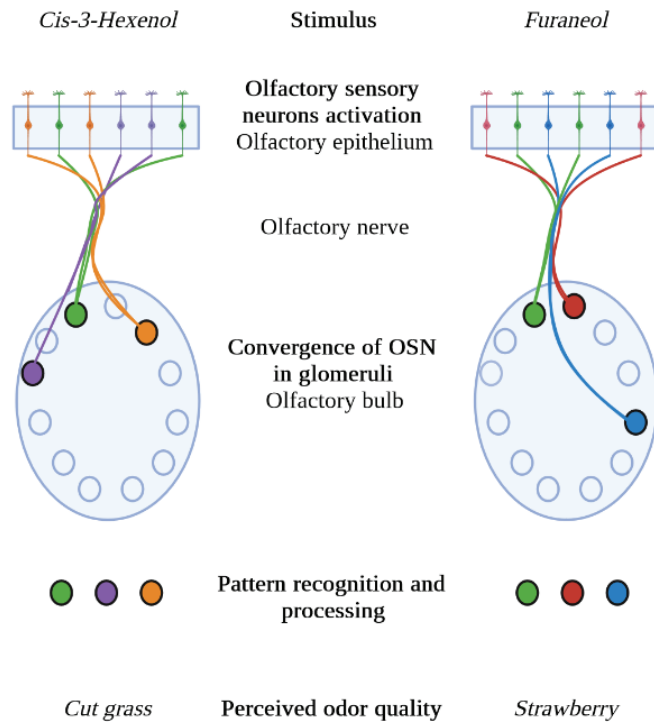


Figure 4: OSN projection on glomeruli
 (Adapted from Krautwurst et al., 2008, figure created by the author on BioRender.com)

OB cell axons then project to different brain regions, such as the anterior olfactory nucleus, piriform cortex, olfactory tubercle, amygdala, or entorhinal cortex. The set of regions receiving direct projections from the OB cells forms the primary olfactory cortex (see Lane et al., 2020 for a review of the regions of the primary olfactory cortex). The information is then transmitted to other regions of the brain, such as the orbitofrontal cortex and the hippocampus, forming the secondary olfactory structures.

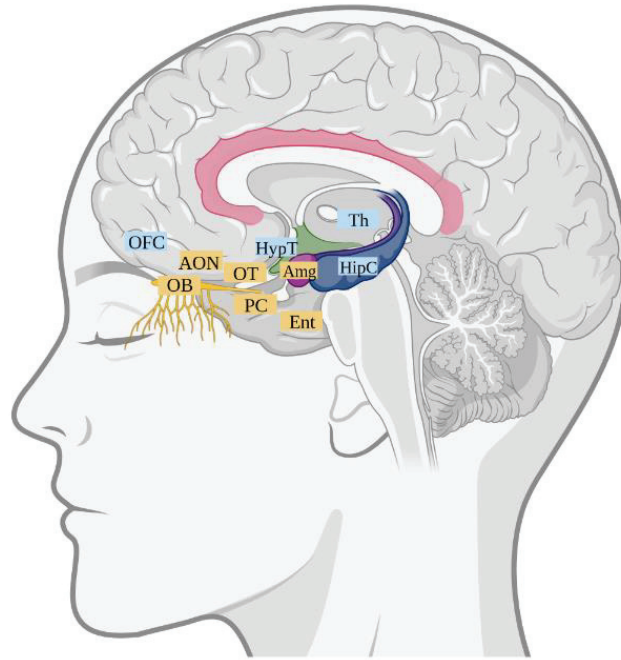


Figure 5: Primary (yellow) and secondary (blue) olfactory cortex

Amg: Amygdala, AON: Anterior Olfactory Nucleus, OB: Olfactory Bulb, OT: Olfactory Tubercle, Ent: Entorhinal cortex, PC: Piriform Cortex, HypT: Hypothalamus, HipC: Hippocampus, OFC: Orbitofrontal cortex, Th: Thalamus

(Figure created by the author on BioRender.com)

In a nutshell, the activation of olfactory neurons and further cortical areas lead to the perception of a smell. The entity emitting the blend of specific volatiles molecules emits a message, about its presence and its properties (e.g. its edibility). This message is then carried to the nose by the spreading of this specific blend of molecules into the air. When the molecules bind to the olfactory receptors, the chemical message is transduced into a nervous message. A smell is then the result of the neural and cognitive processing of this nervous message. A smell is a subjective perception resulting from the processing of the initial chemical message.

Therefore, the physical source, by producing the chemical message initially diffused in the air, shapes the nervous signal resulting from the transduction of the chemical message. The perception of smells is thus, at least in part, conditioned by their physical sources.

1.3. Natural smell, a smell emitted by a natural physical source

Considering the close link between the smell, i.e. the subjective perception, and its physical source, i.e. the physical entity emitting it, one assumption might be that a smell is natural because it is emitted by a natural object (Figure 6). More specifically, the chemical message

sent by the physical source may carry information about the naturalness of the physical source, then shaping the perception of the smell's naturalness.

Indeed, as odors are cues of the presence of objects in our environment, just as odor informs about the edibility of the source, odor could inform about the naturalness of the source. The smell of a natural physical source should therefore be perceived as natural. On the contrary, the smell of diesel fuel indicates the presence of a manufactured object, and would be perceived as artificial. Moreover, since the human sense of smell is able to recognize subtle variations in the composition of odorants, human transformations of objects could be recognized by olfactory perception. An image of a carrot can tell whether the carrot is raw, or whether it has been cut and cooked. As in the visual modality, the smell of the cooked carrot is different from that of the raw carrot, making accessible through its smell the information that the carrot has been processed. Human influence on an object would thus be perceptible via olfaction.

Furthermore, some artifacts are also designed to mimic natural kinds, such as flavorings. Although the chemical differences between natural kinds and flavorings are variable, some differences in their physicochemical properties could lead to discrimination between the natural kinds and its artifactual representation. First, the chemical composition of natural odorants is generally more complex than that of flavors or fragrances. For example, a strawberry emits hundreds of aromatic molecules, while a strawberry flavoring does not exceed a few dozen different molecules (McGorin, 2001). Therefore, this difference in complexity could be perceived and interpreted as a difference in naturalness. In addition, some fragrances or flavors are said to be natural, because the molecules are extracted from a natural source, while for others, the molecules are obtained by chemical synthesis. This difference in the production process leads to different perceptions of the naturalness of the flavor, with natural flavors being perceived as more natural than synthetic ones (Murley & Chambers, 2019). However, it is less clear whether odors from natural or synthetic molecules can be discriminated in terms of naturalness.

To conclude, the above discussion of the naturalness of the physical source suggests that smells' naturalness might be modulated by the naturalness of their physical source. However, as we will see in the second part of this introduction, smells are related but not confounded with their physical source. Therefore, the naturalness of smells may also rely on perceptual features of the smell.

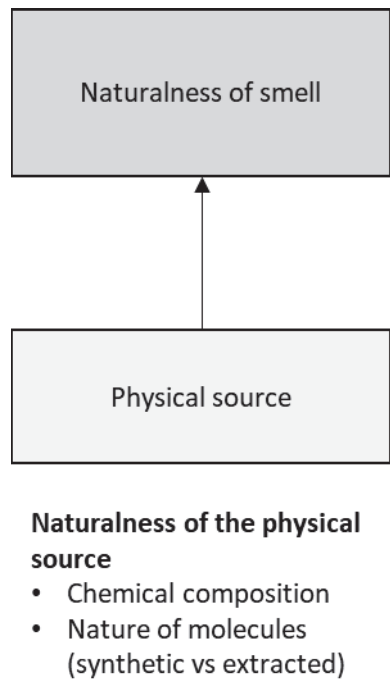


Figure 6: Perception of smells' naturalness is shaped by the naturalness of the physical source

2. The perceptual features of smells' naturalness

2.1. The emitter is not the message

Although related, the physical source and the resulting perception of smell should be distinguished, as they are distinct objects, with distinct properties. In a sense, without a nose, there is no smell.

The emitter, i.e. the physical entity emitting the volatile molecules, is a multisensory entity, with physical and chemical properties. This entity is not reducible to its smell, as it has more properties than what can be carried by the mixture of molecules alone. For example, the smell of a strawberry does not inform us about its size or shape. Similarly, a visual image is a two-dimensional representation of the object photographed, and this object is more than its representation. The visual image does not provide the smell of the strawberry photographed for example (although its color could be a cue of this smell). On the other side, the smell is also not reducible to its emitter. A good marker of this difference is the interindividual variability in the perception of smell while the source is identical. Taking a source, e.g. a jar containing odorous liquid, one might obtain different perceived smells depending on the person smelling the jar.

One of the main factors explaining interindividual variability in olfactory perception is linked to genetic variability. Indeed, variability in the genes coding for olfactory receptors yields

phenotypic variability, and therefore variability in smell perception. Two examples of genetic variability resulting in differential perceptions are particularly famous. The first one is the perception of coriander. Some people perceive it as green and fruity, while others perceive it as soapy. This perceptual variability is due to a genetic variation in the olfactory gene receptor OR6A2 (Eriksson et al., 2012). The second example is the genetic variability responsible for differences in the perception of the molecule of androstenone (Keller et al., 2007; Wysocki & Beauchamp, 1984). This derived-steroidal compound is perceived as sweaty and urinous by some persons, as sweet and floral by others, while some people are even unable to smell it (specific anosmia) (Keller et al., 2007). This difference in perception comes from a genetic variability of the OR7D4 gene, resulting in modification of the structure of the receptor and thus its response to the molecule of androstenone. Moreover, in the case of androstenone, genetic variability leads to differences in quality perception as well as intensity perception (Wysocki & Beauchamp, 1984; Keller et al., 2007).

Other factors of variability are related to the context in which the smell is perceived. The physical parameters of the environment, such as the temperature or humidity, can modulate the way the chemical bouquet reaches the olfactory receptors. Moreover, other contextual elements can affect smell perception. For example, the presentation of smells with stimuli from other modalities, such as colors, images or sounds can influence olfactory perception. Colors have been shown to influence the evaluation of smell pleasantness (Zellner, 2013; Zellner et al., 1991), smell intensity (Koza et al., 2005), or smell identification (Zampini et al., 2008; Zellner et al., 1991). Providing information to the participants also influence their perception of ambient smells, as information on safety of smells influence for example their perception of intensity (Dalton, 1996).

The characteristics of the smeller also modulate smell perception: the physiological state such as satiety state, hormonal cycle, or pregnancy state (Rouby et al., 2009) (Rouby et al., 2009). Many other factors related to the smeller have been found to affect smell perception, such as culture, age, gender or semantic knowledge (Ferdenzi et al., 2013; Rouby et al., 2009).

Thus, beyond their connection, the odor is an entity distinct from its physical source. The perceptual content, the smell, must be distinguished from the physical entity that emits the molecules. Perception of a smell is an interpretation of chemical information (Barwich, 2020), and is therefore different from this information.

2.2. The complex relationship between the physical source and the perceptual level

This distinction between the source, the chemical message, and the smell is of particular importance as the connection between the chemical level and the perceptual level is far from being obvious.

Intensity perception is a good example of the complex relationship between these two levels. Indeed, chemical dimension, and especially the concentration of odorants, partially determines intensity perception (Cain, 1969). Increasing the concentration of odorants leads to an increase in the perception of intensity in most cases... but not always. From a certain level, the increase in the concentration of the odorant no longer leads to an increase in the perception of the intensity, which remains stable as the relation between perceived intensity and chemical concentration is not linear (Chastrette et al., 1998). Moreover, characteristics of the smeller (age, sensibility), as well as contextual factors (associated colors, information on smells safety) also modulate intensity perception (Dalton, 1996; Hummel et al., 1997; Koza et al., 2005; Zellner et al., 1991).

The complexity dimension is also interesting to illustrate chemical and perceptual independence. Most of the objects in our environment emit a complex blend of volatile odorant molecules. The smell of coffee is for example composed of over 800 molecules. And yet, the smell of coffee is perceived as a discreet event, as a unitary percept (Stevenson & Wilson, 2007). The complexity at the chemical level is decorrelated from the perception of complexity at the perceptual level.

The last element that deserves to be noted, is that the code unifying the chemical characteristic of molecules, and the perception of smells is still not understood, despite years of research on this subject. Some very similar molecules lead to different perceptions of smells. For example, R-(-) Carvone is perceived differently from S-(+) Carvone, although the molecules differ only by their 3D structures (Pike et al., 1988). On the contrary, the smell of musk can be elicited by different molecules, with quite different chemical structures (Barwich, 2020). Therefore, it is unsure to predict perceptual features of a smell based on the chemical properties of its physical source.

2.3. Naturalness, a perceptual feature of the smell

In summary, smells, although related to their source, are thus distinct from it. Therefore, in addition to the physical source, the perceptual level has to be considered to evaluate the naturalness of smells. Therefore, we may hypothesize that, although to some extent conditioned by the naturalness of the physical, we may expect that perception of naturalness of the smell is related to its perceptual features (Figure 7).

In other modalities, visual (e.g. color) or haptic (e.g. roughness of paper) has been found to modulate naturalness perception (Deliza et al., 2003; Labbe et al., 2013). Moreover, for olfaction, previous research found a link between pleasantness and naturalness evaluation of smells. Indeed, Apaolaza and colleagues (2014) found that increasing the perception of the naturalness of smells also increases the rating of smell pleasantness. Rachel Herz (2003) also found that positive smells were perceived as more pleasant when presented as coming from natural odorants compared to synthetic odorants. Moreover, investigating the perception of food images, Foroni and Rumiati (2013) found a negative correlation between the level of transformation and familiarity and a positive correlation between the level of transformation and emotional arousal. In line with these results, Padulo and colleagues (2018) found that natural foods were rated as more pleasant, typical and familiar, but as less arousing than transformed foods.

Therefore, in addition to the physical source naturalness, the perceptual level has to be investigated to understand the perception of the naturalness of smells. However, perception is not exclusively driven by the stimulus' sensory properties (bottom-up), but is also the result of the activation of information in long-term memory (top-down) (Solso et al., 2007). In addition to the sensory features of the stimuli, activation of semantic concepts, expectations or beliefs have the ability to influence the perception of smells. The cognitive level should thus also be investigated to fully understand the perception of the naturalness of smells. Moreover, among cognitive factors modulating olfactory perception, elements influencing the identification of smells' sources may be of particular interest.

3.1. The distinction between the physical source and the identified source

Contrariwise to other sensory modalities, the object associated with the smell, the identified source, does not necessarily correspond to the physical entity emitting the smell.

Indeed, we sometimes misidentify the smells. Smells are often associated with cues of the object emitting it, such as visual cues. For example, we see most of our food before eating it. Thus, it seems easy to associate the smell with its actual source, because the information provided by the visual and olfactory modalities are congruent. However, when no other cues than smells are provided, the identification of smells is much more difficult. Many studies showed that participants often misidentified smells, even familiar smells (Cain & Krause, 1979; Engen, 1987). In these cases of misidentification, the objects associated with the smell, i.e. the identified source, thus differs from its actual physical source, i.e. the odorant emitting the smell.

Another example of dissociation between the physical source and the identified source comes from the development of food technology and fragrances. Indeed, in most of our daily life products are flavored or perfumed. We can find strawberry-flavored yogurt or toothpaste, shampoo with an apple fragrance, and candles with a citrus smell. Moreover, when referring to the smell, we may describe it as an apple smell rather than a perfumed shampoo, even if we know that there is no trace of apple in the shampoo. Thus, the term "apple smell" has gained somewhat independence from the traditional source which is real apples.

This independence between the physical source and the identified source might have some important implications in the perception of smells' naturalness. Therefore, by referring to the physical source, we will focus on the properties of the physical entity behind the smell. On another side, by referring to the identified source, we will refer to the semantic label associated with the smell. Although these two terms can designate the same object, they can also refer to different objects with different properties, such as in the cases of misidentification (Lafraire, 2013).

The interest in identification processes is two-fold. First, the linguistic of smells relies dramatically on references to the source. This linguistic connection is that tight that odors and sources are sometimes difficult to disentangle, which may result in a transfer of properties from the source to the percept. Secondly, evidence of cognitive modulation of smell perception by semantic labels has been shown in previous research.

3.2. Linguistic of smells: no name for smells

A digression into odor linguistics might provide some elements to understand the importance of smells' sources for smell perception. Linguistic analysis of ordinary language contributes to the understanding of smell perception.

The element of smell linguistic that is probably of most interest to understand the naturalness of smells is the following: smells, in general, have no name (in French and Anglo-Saxon cultures at least, but this point is cultural dependent as other cultures have specific names for smells, see Dubois & Resche-Rigon, 1997; Wnuk & Majid, 2014). Unlike other sensory modalities, our languages do not have specific names for smells. In the visual domain, it is possible to name colors and shapes, independently of the object from which they come. Likewise, independently of the food consumed, it is possible to describe its taste, like acidity, saltiness, or sweetness for example. Even in the auditory domain, although this language requires special learning, it is possible to give a name to the different notes (G, B, C, etc.). For olfaction, with the exception of certain smells and perfumes, we most often refer to entities in the world to name and designate smells, by saying that it is the smell **of** + an object, such as it is the smell of cheese.

This “of”, is especially important in French for example.

(1) The smell of rose

L'odeur de la rose

(2) The rose smell

**L'odeur rose*

(3) The color of rose

La couleur de la rose

(4) The color pink

La couleur rose

The syntactic analysis highlighted that form (1) is correct in French, but form (2) is not, while both forms (3) and (4) are correct (David, 2002). Colors can be the property of an object (form 3), but also have their own names (form 4). Moreover, most of the odors have not acquired their conceptual independence from their source, as form 2 is incorrect. Even in English, form 2 does

not provide the smell's name, but the smell's source. As Daniel Dubois (2006) put forward, this absence of names for smells may result in confusion between smell's properties and the properties of the source, as for example in the case of sweet smells. In this case, the gustatory property of the smell would be transferred to the smell. Moreover, this lack of odors' names could explain the strong influence that source label has on odor perception.

3.3. Evidence of modulation of smell perception by identification process and semantic labels

In the scientific literature, evidence of the effects of semantic labels on the perception of smell has been put forward. For example, De Araujo and colleagues (2005) found that naming odors modulated the perceived naturalness of odors, even though the odorant was the same for all participants. Indeed, the molecule of isovaleric acid was perceived as less unpleasant when associated with the label "cheddar cheese" than when it was associated with the label "body odor" (de Araujo et al., 2005). Results from other studies found the same modulation effect of smells' labels on the perception of odor pleasantness, as the association of a positive source's name (e.g. "green mango" vs "Hospital disinfectant", Djordjevic et al., 2008, p.387) to the smell increases evaluation of the smells' pleasantness (Bensafi et al., 2007; Djordjevic et al., 2008; Herz, 2003; Herz & von Clef, 2001; Manescu et al., 2014). Moreover, other results found that providing labels to name the smells also influences the perception of intensity and arousal (Djordjevic et al., 2007), as well as physiological responses to smells, such as skin conductance and sniff volumes (Djordjevic et al., 2007) or brain activation (de Araujo et al., 2005).

Interestingly, in the case of naturalness, Rachel Herz (2003) found that providing labels referring to smell's naturalness (e.g. "this is natural rose" vs "this is synthetic rotten egg", Herz, 2003, p.598) modulated the evaluation of pleasantness of smells. Post-hoc tests revealed that smells associated with a source pleasant and natural were perceived as more pleasant than smells associated with a source pleasant and synthetic. Moreover, in their first condition, participants categorized smells as natural or artificial. The author observed that naturalness effect on pleasantness was significant depending on participants' categorization (natural smell being more pleasant) irrespective to the actual naturalness of the odorant (artificial odorants were perceived as more pleasant when falsely categorized as natural). However, the author found no difference in pleasantness ratings between natural or synthetic sources for unpleasant labels.

Thus, the association of a smell with a source through identification may influence the perception of this smell. Encountering this smell with cues of the object emitting it, like visual cues, might thus lead to memorizing it as the smell **of** this object, like the smell of lemon or cheese. Then, the recall of this odor as the smell of this object would lead to the recall of the properties of this object, and the association of these properties with the smell, e.g. edible, sweet, or natural.

3.4. Natural smell, a smell identified as a natural entity?

Considering the cognitive influence of the identification on smell perception, we might consider also the cognitive level in the perception of smell naturalness. Whatever the actual physical source is, would a smell be natural because smelling like a natural object? A smell, even coming from a synthetic odorant might be perceived as natural based on its identification.

In line with this assumption, Herz (2003) and Hermmerring and colleagues (2016) found that smells from natural odorants were not discriminated from smells from synthetic ones, suggesting only a weak effect of the physical source's naturalness on the perceived naturalness of smells. However, as we developed above, smells are related to their physical source as it shapes the chemical message received in the nose. We thus face the problem of the level of analysis that should be considered to determine the naturalness of smells: the level of the physical source's naturalness, the perceptual level, and the cognitive level.

4. Conclusions

In this section, we have considered different levels of analysis of odor perception: the physical source, perceptual and cognitive levels to understand the determinants of odor naturalness (Figure 8). Each level provides a piece of the puzzle of odors' naturalness.

The exploration of the **issue of the physical source** has brought to light the neurophysiological basis of olfaction and the way it conditions olfactory perception. The chemical message sent by the physical source of the smell shapes olfactory receptors activation and therefore the initial perceptual message. Therefore, the chemical blend of molecules emitted by the source may carry information about the naturalness of the source, which may then be interpreted during odor processing and result in the perception of a natural or artificial smell.

Therefore, our first hypothesis is that: ***The naturalness of the physical source influences the perception of the naturalness of smells (H1).***

However, the consideration of the **perceptual level** highlighted that olfactory perception is not only determined by the physical source. First, the emitter, the physical source, is not confounded with the interpretation of the signal it sends, the smell. Indeed, a smell is a subjective perception, and the same source may result in different smells depending on the contextual parameters and the characteristics of the smellers. Secondly, the relationship between chemical properties, such as molecular concentration, and perceptual features of smell, such as intensity, is far from being simple and well understood. Thus, the perceived naturalness of an odor may, to some extent, differ from the naturalness of the source.

Thus, we assume that: *The perceptual features of the stimuli influence the perceived naturalness of smells (H2).*

Finally, we discussed factors that could modulate the perception of naturalness at the **cognitive level**. One of them seems particularly interesting: the semantic label associated with the odor through the identification process. Indeed, odors are linked to the semantic label because odors do not have their own name in Western cultures. Moreover, the effect of semantic label on odor perception has been demonstrated in previous research.

Our third hypothesis is thus that: *Evaluation of naturalness varies with the identification of smells (H3)*

Moreover, as we have mentioned in the first and second chapters, the question of inter-individual variability must also be considered. Indeed, we observed that, since naturalness is polysemous and vague, the definition of naturalness varies somewhat from one person to another. Moreover, due to genetic variability, but also to other sources of inter-individual variability such as differences in beliefs or background knowledge, odor perception is also highly subject to inter-individual variation.

Therefore, we assume with a fourth hypothesis that: *the naturalness perception is subject to high interindividual variability (H4).*

In our research, we thus investigated the effect of these different levels of analysis on the perception of the naturalness of smells (Figure 8). However, the relationship between these levels and their respective influence on perceived naturalness is unclear. For example, can it occur that a natural odorant is perceived as artificial, the perceptual level ignoring the chemical basis of the smell? The most problematic situation would be that, although the physical source

is natural, the identification of the odor results in an identified artificial source (and vice versa). In this case, what would be the evaluation of the odor at the perceptual level? To what extent the assessment of naturalness based on one of the three levels does predict the assessment of naturalness for the other two levels is an open question. The relationships between each level are thus unclear, as cases of dissociation may occur, with one level categorized as natural and another as artificial.

The main objective of this research work is thus **to investigate the contributions of the physical source, perceptual, and cognitive levels (mainly through the identification process) to the perception of smells' naturalness**. The research question that will lead us throughout this research is therefore to determine the respective contributions of each level to the final perception of the naturalness of odors. In addition, as there is inter-individual and cultural variability in the definition of naturalness and olfactory perception, both were considered throughout our research.

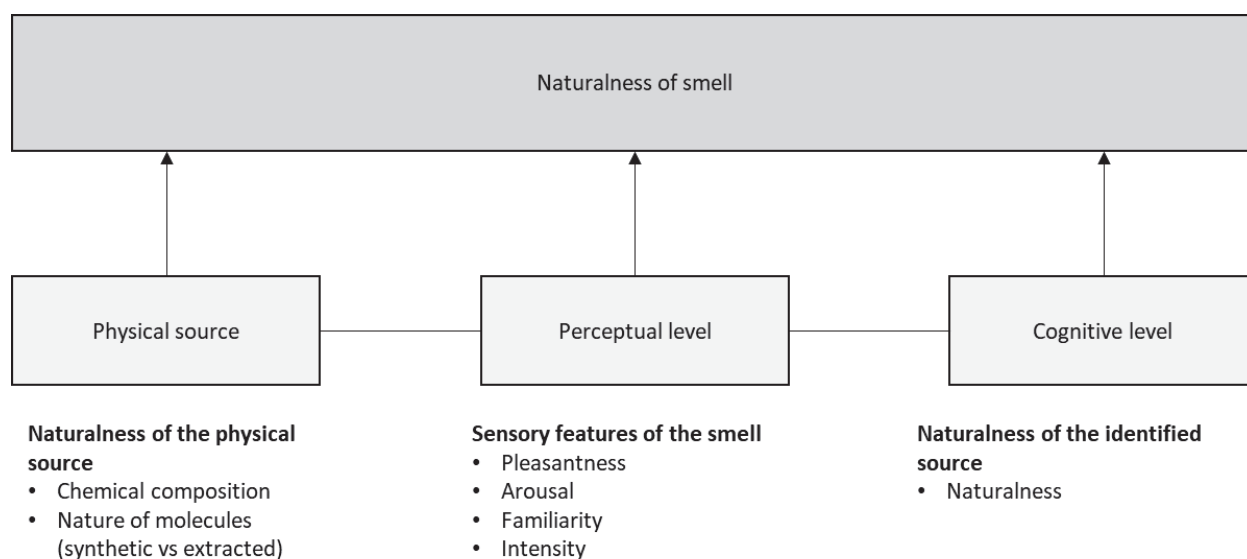


Figure 8: The three levels of analysis of smells naturalness perception

Our research is divided into four studies.

Study 1 (Chapter 3) aimed to clarify the notion of naturalness and to develop a scale to capture the inter-individual and cultural variability of attitudes towards naturalness. The development

of such scale also aimed to investigate the relationship between attitude and perception of naturalness (cognitive level).

In **Study 2** (Chapter 4) focusing more specifically on hypothesis 2, and to a lesser extent on hypotheses 1 and 3, we were interested in the sensory attributes associated with the naturalness of odors.

Then, to complete the first results obtained with study 2, we conducted **Study 3** (Chapter 4) to investigate the effect of perceptual and cognitive factors on the perception of the naturalness of odors, allowing us to test the fourth hypotheses formulated in the present thesis.

Finally, in **Study 4** (Chapter 5), with the implementation of implicit tests in France and the United States, we studied the cross-modal aspect of the definition of odor, which allowed us to test more particularly our hypothesis 3, and to a lesser extent our hypothesis 2.

Part B – Empirical Research

Chapter 3- Assessment of attitude toward natural products

In this first experimental chapter, we address the issue of interindividual variability. Indeed, human attitudes toward naturalness have been dynamic across time and cultures. Today, although the trend of demand for natural products is widespread throughout the world, studies conducted on the subject have also reported inter-individual variability in the attitude towards naturalness. In addition, a review of the literature on the measurement of attitude toward naturalness revealed some gaps in the existing tools, as well as a limitation on the scope of these measures since they were restricted to the food domain.

The objectives were therefore to complement the existing scales with less considered dimensions of naturalness, and to develop scales measuring attitudes towards inedible products. In addition, the new tools made it possible to compare attitudes across product categories. Finally, the goal was also to develop new tools to incorporate into our future research to study the relationship between attitude toward naturalness and perception of naturalness.

Study 1 – Product Naturalness Scale (PNS): development and validation of a new scale to measure attitudes toward naturalness for different categories of products

Product Naturalness Scale (PNS): development and validation of a new scale to measure attitudes toward naturalness for different categories of products

Dantec M^{1,2,3§}, Allain H¹, Yvert N¹, Bensafi M³, Lafraire J²,

¹ Marketing, Sensory & Consumer Research, V. Mane Fils, Le Bar sur Loup, France

² Institute Paul Bocuse Research Center, Ecully, France

³ Lyon Neuroscience Research Center, CNRS-INSERM-University of Lyon, France

IN PREPARATION

[§] Corresponding author

Centre de Recherche de l'Institut Paul Bocuse

Château du Vivier

1A Chemin de Calabert

69130 Ecully - FRANCE

Email: morgane.dantec@institutpaulbocuse.com

Abstract

Human attitudes toward nature have been dynamic throughout the ages and across cultures. Today, in response to the industrialization of food processing and urbanization, there is a growing interest in the natural. Although this trend is widespread throughout the world, attitudes toward naturalness vary among consumers. Therefore, the purpose of this research was to extend and complement existing research on attitudes toward natural products to aspects of naturalness that have received little attention and to inedible product categories. This paper presents the development and validation of three scales measuring attitudes toward natural products for three product categories: food, personal care products, and household products. Our results show that the developed scales satisfactorily meet the gold standard for scale validation. Furthermore, in addition to capturing inter-individual variability in attitudes, our results revealed that consumers' attitudes are more positive toward natural foods than toward inedible products. These results provide insight into the trend of natural food consumption and provide new tools to measure these attitudes.

Keywords: Attitude, Naturalness, scales, psychometrics validation, Category of product

1. Introduction

The human disposition toward naturalness has been dynamic through history and culture (Descola, 2018; Worster, 1994). In early Christianity, Nature was seen as a source of demonic threats and repressible bestial instincts that had to be arranged according to humans' needs (Descola, 2018; Worster, 1994). In occident, the scientific advances of the 18th century further legitimized the domination of Nature by reason, and its commodification to serve the human economy. A contrario, the proponents of a romantic vision in the 18th and 19th centuries endorsed reverence and humility toward Nature (Worster, 1994). They emphasized the instrumental benefit of nature protection for the human economy, but also that protecting the natural world is right (Leopold, 1949). Moreover, despite a palette of attitudes toward Nature (Kellert, 1995), Edward O. Wilson (1993) hypothesized that humans have innate biophilia, i.e. “an innate tendency to focus on life and lifelike processes” (Kellert & Wilson, 1995, p.1).

In the 20th century, major technical upheavals (e.g. generalization of the use of fertilizers and pesticides) led to an increase in yields, but also to deep changes in way of living and relation to nature. In the 1960s decade, the negative impact of the pesticide DDT on biodiversity raised awareness of the threats of chemicals to the environment and health (Lockeretz, 2007). At the same time, growing distrust of all synthetic food additives and industrial foods has increased the demand for less processed and more natural foods as a symbol of quality (Lockeretz, 2007). While processed foods have previously been seen as an improvement in food safety and preservation, the perception of natural foods became more positive during this period (Schösler et al., 2013). In this context, there is nowadays a growing interest in naturalness from consumers, especially for food (Evans et al., 2010). Many studies, conducted in different countries, including the United States, France, Japan, and Poland, showed that a majority of consumers have a positive attitude toward natural foods (Román et al., 2017), i.e. a positive evaluation of natural foods on a continuum from favorable to unfavorable (Albarracin & Shavitt, 2018). This trend is particularly important for food, but also concerns other product categories, such as cosmetics or household products (Kim & Seock, 2009; Lin et al., 2018).

However, consumers' attitudes toward natural foods have been measured in different ways. A first approach is the method of self-report, by asking participants to evaluate how favorable they are toward the studied object (Edwards, 1957). Paul Rozin and colleagues (2004) applied this method, by asking participants ““Do you think NATURAL is generally a good thing?”” with

a yes/no answer (Rozin et al., 2004, p.150). However, this method is quite liable to social desirability or self-presentation bias, i.e. participants answer based on what they perceived as being socially acceptable rather than personal feelings, which may introduce noise in the measurement of attitudes (Graeff, 2005). Other studies measured dispositions toward naturalness through attitudinal scales (Román et al., 2017). An attitudinal scale is a set of statements, or items, measuring the evaluative feelings of participants toward this object or concept. Participants rate their level of agreement with these statements, usually on Likert scales. Statements should distinguish between participants with favorable attitudes, from those with unfavorable attitudes (Edwards, 1957). Besides, although a majority of consumers have a positive evaluation of natural foods, previous research on attitude toward naturalness found inter-individual variability in the attitude toward natural foods (Bäckström et al., 2004; Roininen et al., 1999; Steptoe et al., 1995).

Nevertheless, items used to measure attitude toward naturalness vary among attitudinal scales. In 2017, Román and colleagues reviewed how the attitude toward natural foods has been measured. They identified 72 studies measuring consumers' preference for natural foods. Their first observation is that, despite the number of studies, there is no consensual definition of naturalness. For example, Steptoe and colleagues (1995, p.281) based natural food definition on “the use of additives and natural ingredients”, while Roininen and colleagues (1999, p. 75) defined natural food as those “that do not contain additives and are unprocessed”. Because the definition and content of the scale differ between studies, the purpose measured by these scales may also differ, making it difficult to compare and generalize results across studies. A clarification is thus needed about the naturalness definition.

Naturalness is a vague and polysemic concept, subject to interpretation by consumers and researchers (Borghini, 2014; Siipi, 2013). Natural can for example refer to familiarity, as it is natural to greet your colleagues when you arrive at work. The term "natural" also refers to innate, such as the “natural gift” of playing the piano (see Siipi, 2008 for a review of naturalness polysemy). Moreover, as Helena Siipi puts forward (2013) in the case of food, “naturalness” is commonly related to the lack of human influence.

However, this meaning of naturalness remains vague, as “lack of” and “human influence” are still open to interpretation. In the strictest definition, natural entities would be those that have not been transformed by human influence, even indirectly. In the age of global warming,

biodiversity loss, and widespread plastic pollution, one wonders if such entities still exist. In a slightly more liberal view, naturalness would be close to wilderness. Indeed, if wild blackberries are indirectly influenced by human activities, they develop spontaneously without humans' will to breed them (Borghini, 2014; Sandin, 2017). In the food domain, other authors as defined natural food as fruits and vegetables (Rumiati & Foroni, 2016), or as “one that had not been changed in any significant way by contact with humans. It could have been picked or transported, but it was chemically identical to the same item in its natural place” (Rozin et al., 2004, p.148). In this view, natural food would then be close to raw food. However, since most of our food comes from domesticated species, they thus bear the traces of years of genetic selection by humans, which is in contradiction with the previous definition of “lack of human influence”. Even more, naturalness is sometimes used to qualify entities such as shampoo. Since detergent and perfume seldom melt in a plastic bottle in nature, using the “natural” term for such entities seems contradictory. This apparent paradox might be explained by the difference between natural whole products and natural compound products (Borghini, 2014). Taking the example of food, natural whole food is natural when it has not been modified during its production, others than by action to make it suitable for human consumption, such as apple. Moreover, compound food is natural when made from natural ingredients, such as apple pie with natural ingredients. Yet, this definition is not in accordance with the one above, that natural entities have not been influenced by direct human action. Which one should then be chosen? The different definitions of naturalness seem to differ in the degree of human influence set as the cut-off between natural and artificial entities.

Taking into account the existence of ambiguous cases like food, which are neither natural entities nor human-made artifacts, some authors suggested that naturalness would then be better represented by a continuum rather than as a dichotomy (Gelman, 1988; Lepiller, 2016). One of the main advantages of naturalness as a relative attribute is that it allows the comparison of naturalness entities. A product would be “natural” because it is the most natural representative product for a given category rather than a natural entity per se. For example, raw farmed food, although not being a natural entity per se, would be natural in comparison to transformed food. Moreover, different dimensions, such as ingredients type or production process, may influence the ranking of products as more or less natural. During the past decades, different dimensions have been identified as modulating the place of a product on the naturalness continuum. These

dimensions, as they influence naturalness perception, should thus be taken into account when developing a scale measuring attitude toward naturalness.

However, except for the scale of Michel et al. (2019), the scales measuring attitude toward naturalness are subscales of broader scales aiming to measure broader concepts, like as example food choices (Step toe et al., 1995), willingness to try new foods (Bäckström et al., 2004), or attitude toward health and hedonic characteristics of foods (Roininen et al., 1999). Therefore, because their purpose was not to specifically measure attitude toward naturalness, these scales did not aim to cover the wide range of dimensions that influence naturalness perception. As the scale from Michel and al (2019) was developed following the review of Roman and colleagues (2017) of the already existing scales, it might also miss some sub-dimensions of naturalness. This lack of exhaustiveness and variability in the measure of naturalness may be problematic for two reasons. The first one is that it makes the comparison of results between studies questionable, as they might measure different constructs. However, despite differences between the scales, Michel and colleagues (2019) found high correlations between the scores obtained with six of these scales (Bäckström et al., 2004; Michel & Siegrist, 2019; Pula et al., 2014; Renner et al., 2012; Roininen et al., 1999; Step toe et al., 1995), with correlations varying from .69 to .89 (Michel & Siegrist, 2019). The second reason is that some critical dimensions underlying attitude toward naturalness may be lacking, hiding sources of inter-individual variability. Therefore, considering the issue of exhaustiveness, our first objective was to complete the scale developed by Michel and al. (2019) with new dimensions identified in the literature as modulating naturalness.

Furthermore, developed scales focused on natural foods, while demand for natural products is far from being restricted to the food domain (Kim & Seock, 2009; Lin et al., 2018). This focus on food leads to a significant lack of knowledge about the attitude toward other consumer goods. Indeed, food is a special category of product, and results in the food domain may not be generalizable to other product categories. Moreover, specificities of the food domain may also explain differences in attitude toward naturalness between categories of products. Rozin and colleagues (2004) found for example that preferences for naturalness depend on the category of products, as preferences for naturalness were stronger for food than for medicines. Variability in attitude toward naturalness across product categories could be underpinned by the contagion effect, i.e. a permanent transfer of properties from one object to another after a brief contact (Rozin et al., 1986). Indeed, food is ingested, and thus, has a strong power of chemical and

moral contamination on the body (Rozin, 2005). In addition, the belief that natural foods are healthier than processed foods is common (Román et al., 2017; Rozin et al., 2004). Healthiness would even be one of the drivers of natural product preferences (Rozin et al., 2004). Thus, given that the potential of contamination and health harm is especially high for food, a first assumption would be that attitude toward naturalness would be more positive for food than for inedible products. As no scale exists to measure attitude toward natural inedible products, the second objective of this study was thus to develop and validate an attitudinal scale to measure it.

To be able to compare attitudes toward naturalness for different categories of products, we developed three scales, each one for a category of products. Products' category included the following categories: food, personal care products (PCP), and household products (HP). We chose two inedible categories of products for two reasons. First, even if the food category is wide and gathers heterogeneous items, this category is more specific than “inedible products”. Therefore, we targeted product categories trying to keep the same level of generality as the food category. Secondly, as highlighted above, contamination effects and health considerations are some of the drivers of naturalness preferences. Therefore, the two inedible categories were chosen in order to modulate the distance between the products and the user’s body, and then the potential contamination effect. The objective was to explore how the attitude toward natural products would differ between products with proximal (personal care products) or distal utilization (household products). To ensure that measures are homogeneous and target the same construct, items were identical between scales, with only the name of the category of product differing.

2. Preliminary experiment: item generation and item reduction

2.1 Method

The development of a scale follows different phases: items development, scale development, and scale validation during which the psychometric properties of the scale (e.g. reliability, convergent or divergent validity, dimensionality, or predictive value) are assessed (Boateng et al., 2018). The performance and relevance of the final scale depend upon the quality of the items. Items development is thus a critical phase. Items have to be relevant to measure inter-individual variability in the attitude toward naturalness, but also to cover the entire range of this domain (Edwards, 1957). Items should also be simple, non-ambiguous, and easily

understandable by everyone. Thus, the first step of scale development is the identification and definition of naturalness and its boundaries. The following steps are the generation of items included in the scales, the selection of the most relevant ones, and finally the validation of psychometric parameters of the final version of the scale.

2.2.1 Items and scales development

Item generation

The scale developed by Michel et al. (2019) based on Román and al. (2017) review was set as a starting point for items development. Then, the objective was to complete it with dimensions found in the scientific literature as related to naturalness and not included in their scale.

Various factors have been identified as modulating the naturalness of a product, preeminent ones being the type of ingredients the product is made with and the production process (Román et al., 2017). Indeed, because of the contagion effect, the use of unnatural ingredients (even very small amounts) dramatically reduces the naturalness of a product (Rozin, 2005). Paul Rozin (2005) found that this contagion effect persists even if the unnatural ingredient is then removed from the product. Furthermore, some ingredients have been singled out because of their strong negative influence on the perception of products' naturalness: GMOs, preservatives, additives, artificial colors and flavors, chemicals hormones, and pesticides (Román et al., 2017). Another crucial factor in the modulation of naturalness is the production process. The less processed a product is, the more natural it is perceived (Evans et al., 2010). However, as for ingredients, the type of processes matters. For instance, physical transformation alters less the perceived naturalness of products than chemical ones (Rozin, 2005). These two factors, product content, and production process have been the most widely studied in the literature on factors modulating naturalness (Evans et al., 2010; Román et al., 2017; Rozin, 2005). They are also the most commonly used dimensions in the studies focusing on consumers' preference for naturalness (Pula et al., 2014; Renner et al., 2012; Roininen et al., 1999; Steptoe et al., 1995). These dimensions were included in Michel et al. scale (2019), and the items were divided into three parts: "Ingredients used: Free from", "Ingredients used: Presence of", and "Production process" (Michel et al., 2019).

Furthermore, other dimensions modulating naturalness have been identified but not included in Michel et al. (2019) scale. For example, regardless of the type of ingredients, the length of the ingredients list influences naturalness perception; the shorter the list the more natural the

product is perceived (Cheung et al., 2016). Moreover, the dimensions modulating naturalness perception are sometimes linked to different meanings of naturalness, such as familiarity meaning. Etale and colleagues (2021) found for example that processing techniques perceived as traditional and old alter the naturalness of a product less than new techniques. Their results also put forward that the processing scale (small versus industrial) modulates naturalness perception, process at the industrial scale decreasing the perceived naturalness of a product more than small scale (Etale & Siegrist, 2021). Naturalness has also been confounded with authenticity. The entities existing without human craftsmanship are authentic while artifacts, which are human-made, are not (Siipi, 2013). Authenticity can also refer to purity and realness (Siipi, 2013), and natural products are perceived as purer than artificial counterparts (Rozin et al., 2004). However, no existing scales encompass these dimensions. Similarly, while naturalness is sometimes confounded with wilderness, no items of attitudinal scale about naturalness investigated this issue.

Based on the elements found in the literature, Michel et al. scale (2019) was then enriched with new items about homemade production, industrial products, ingredient list length, use of feral ingredients such as wild plants, authenticity, and purity. In addition, we included statements on expected attributes of natural products as beliefs are also part of attitudes (Edwards, 1957). As Romàn and colleagues (2017) pointed out, the attributes associated with natural products most often included in the scales relate to health and nutrition (Renner et al., 2012; Roininen et al., 1999), environment friendliness (Olbrich et al., 2015), and taste (Tobler et al., 2011). Moreover, although believes that naturalness is more ethical and right than artificial counterparts has been investigated (Leopold, 1949; Rolston, 1995; Soulé, 1995) this dimension has not been included in existing scales and was thus integrated into ours.

Local and organic dimensions, sometimes included in attitudinal scales toward natural food (Bäckström et al., 2004; Renner et al., 2012; Roininen et al., 1999) were not selected as defining features for natural products. Local demand, while close to naturalness demand on many points (Autio et al., 2013; Schösler et al., 2013) is not directly related to the level of involvement of humans in the production process. The organic dimension was already included in the boundaries of natural products definition as it overlaps with the pesticide issue. Moreover, factors modulating the perception of products packaging only, such as the material used or colors, were considered as not relevant to measure attitude toward natural products.

In addition, as our second objective was to develop a scale measuring attitudes toward natural inedible products as well, three scales with the same items were developed. Only the name of the product categories differed between them. The items from Michel et al. (2019) scale were thus adapted to PCP and HP categories.

Items wording

In scale development, the importance of reversed items is still under debate (Weijters & Baumgartner, 2012). To avoid positive answer bias, we included items with a negative evaluation of the opposed concept of natural products (Weijters & Baumgartner, 2012). However, multiple terms have been opposed to natural, such as “artificial”, “unnatural”, “supernatural”, “unfamiliar”, “unusual”, “cultural”, “technical”, “manufactured”, or “transformed” for few examples (Rozin et al., 2004; Rumiati & Foroni, 2016; Sandin, 2017; Siipi, 2013). Some of these words, such as "supernatural", refer to different meanings of natural than the one we follow, i.e. the absence of human influence, and therefore have not been taken into account. Moreover, “artificial” is vague and had little meaning in the case of food. Thus, the opposite of natural food was set as highly-transformed food, which is the highest level of food transformation in food classification (Monteiro et al., 2010). In the case of inedible products, the opposite of natural products was set as synthetic products, which refer to a well-identified chemical transformation as opposed to naturalness (Borghini, 2014). To avoid influencing participants toward a positive evaluation of natural products, we also included positive statements toward highly transformed/synthetic products and negative statements toward natural products (reversed items).

In addition, special attention was paid to the wording and syntax of the statements to avoid ambiguous statements, complex words, long and complex sentences, universals such as “all” or “always”, negative formulation and double negative formulation, or double-barrelled sentences (Boateng et al., 2018; Clark & Watson, 1995; Edwards, 1957).

After the generation of items, each scale had 22 items.

Content validity assessment

After items generation, we assessed content validity to ensure that the items developed were relevant to measure attitudes toward natural products (Boateng et al., 2018). Content validity of our scale was reviewed by 4 experts in psychology and consumer science who previously worked on naturalness. They rated the relevance of each item for each scale (one for Food, one for PCP, one for HP) on a 4 points scale from 1-Not relevant to 4-Highly relevant, and had the opportunity to provide written comments . They also rated the overall understanding of each item on a 4-point scale, from 1- Not clear to 4-Very clear. For each item, we calculated an Item-Content Validity Index (I-CVI index), which is the proportion of experts who rated the item as relevant (Polit & Beck, 2006). An S-CVI (Scale-Content Validity Index) was also calculated for each scale, by calculating the mean of the I-CVIs. I-CVI under 0.75 or S-CVI under 0.8 were considered problematic (see Polit & Beck, 2006 for a methodological discussion on CVI indexes).

In the HP scale, 9 items had I-CVI under 0.75, and 4 of these 9 items also had an I-CVI under 0.75 for Food and PCP scales. Among these 9 items, 5 were deleted, and the 4 others were modified based on experts' comments. Following experts' advice, the wording of 7 other items was slightly modified. To preserve homogeneity between scales, deletion or modification were equivalent for each scale. After the deletion of items, the Food scale had an S-CVI of 0.9, the PCP scale had an S-CVI of 0.8, and the HP scale had an S-CVI of 0.7 (which was close to our criterion). The new version of the scales had 17 items. The new versions were submitted again to the experts, but no modification was requested.

Measurement of the understanding of the items

To minimize the misunderstanding of the items, and thus, measurement error, a naïve panel of French participants was recruited on December 2020 through a mailing list to answer an online survey conducted on Qualtrics©. The survey collected 61 responses, but due to 11 incomplete responses and 3 duplicates, only 45 responses were analyzed (36 females and 9 males, the mean age of the sample was 53 ± 13.5). Participants were first informed of the procedure and the objectives of the study and gave written consent for their participation. They rated their level of agreement with the 17 items on a 7-points Likert scale as if they were completing the scales. Right after, participants evaluated the difficulty to answer the question on a 4-points scale, from

1-Very easy to 4-Very difficult. As participants were recruited from the French population, items developed in English were translated into French with a back-forward procedure.

More than 10% of participants found it difficult to answer 3 items, which were thus deleted, and 2 items were modified following participants' comments as they were considered as not easily understandable by more than 5% of participants. The new version of the scales had 14 items.

2.2.2 Participants and procedure

The aim of this preliminary survey was to collect data enabling the selection of items with the best psychometric quality. Participants were recruited via Qualtrics with quota on age, gender, and educational level to have a representative sample of the French population. To collect enough data to ensure reliable results and powerful statistical analysis, 407 participants were recruited (Clark & Watson, 1995). The sample was composed of 53% of women (215 women for 192 men). The mean age of the sample was 47.9 ± 16.7 ; 10% were between 18 and 24 years old, 15% were between 25 and 34 y/o, 25% were between 35 and 49 y/o, 25% were between 50 and 64 y/o, and 25% were older than 65 y/o. For the educational level, 19% had under C grade or no diploma, 47% had high school level or equivalent, and 34% had a 2 years degree or more. Participants received a voucher of 4.5 euros for their participation.

Participants were first informed of the study objectives and gave written consent. They were informed of the study procedure and completed a demographic questionnaire (age, gender, educational level, and professional category). The scales were then presented in a random order, and items were also randomized within each scale. After completing each 14-item version of the scales, they were given the opportunity to leave a comment. The average length of the survey was 7 minutes.

Data were collected anonymously, and the collection and storage of data respected the rules and regulations of GDPR and CNIL. The study conformed to the Declaration of Helsinki and was approved by the ethics committee of the university's college of general medicine.

2.2.3 Data analysis

Score calculation

For each participant and each scale (one for Food, one for PCP, one for HP), we calculated an attitudinal score. Participants answered each of the 14 items with a 7-points Likert scale. For regular items (i.e. positive attitude toward naturalness), the answer “Strongly agree” was set as “+3” and “Strongly disagree” as “-3”, and the score was reversed for reversed items (i.e. negative attitude toward naturalness or positive attitude toward artificialness). The attitudinal score was then calculated as the sum of the participant's answers. Scores could vary between -42 and 42, the more positive the score the more positive the attitude toward naturalness.

Item reduction analysis

To provide a parsimonious scale, the objective of this preliminary study was to select the items with the best technical quality, i.e. items that were related to each other and were able to reveal variability between individuals. Deletion of items with poor quality should increase internal consistency and decrease measurement error and noise due to the measurement of a tangential construct (Boateng et al., 2018). To delete items, the following criteria were applied: 1) items with poor inter-individual variability, ceiling or floor effect were discarded (Clark & Watson, 1995), 2) items with low item-total correlation (unrelated construct) or with too high inter-items correlations (redundancy) were let aside (Boateng et al., 2018), and 3) after the analyze of the dimensional structure of the scale, items with low loading on dimensional factors or loading with two different factors were deleted. Analyses were conducted with R software, version 3.6.3. We set the alpha level at .05 for all statistical analyses.

2.3 Results

2.3.1 Variability and ceiling effect for items

For the three scales, scores ranged from -42 to 42 ($M=8.5\pm 10.1$ for Food, $M=7.3\pm 10.1$ for Personal Care Products, $M=6.9\pm 10.0$ for Household products). All the items had medium means (between -2 and 2 on the 7-point Likert-Scale from -3 to 3) for the three scales, meaning that there were no ceiling or floor effects (Clark & Watson, 1995). In addition, items showed satisfactory variability between participants as no items were approved or disapproved by more than 95% of participants. Being satisfactory on ceiling and floor effects, and on variability, no item was deleted based on this criterion.

2.3.2 Inter-items and item-total correlations

We analyzed adjusted item-total and inter-items correlations. Inspection of the adjusted item-total correlation revealed that two items (items 7 and 9) had low correlations with the overall score of the scale for PCP scale (correlation of .55 and .52 respectively). These items were thus deleted for the three scales. Moreover, analysis of inter-items correlations showed that two items were highly correlated with others: item 1 was highly correlated (correlation > 0.7) with items 3 and 6, and item 2 was highly correlated with items 8, 10, and 11. Thus, items 1 and 2 were deleted to respect the principle of parsimony.

2.3.3 Factorial analysis

To explore the dimensional structure of the scales, the remaining 10 items were factor analyzed with Promax rotation for each scale (table 1). The optimal number of factors was assessed following Cattell's criterion on scree plot, i.e. the determination of the point where the last important eigenvalues drop appears (Cattell, 1966), and following Kaiser's criterion, i.e. only the factors with eigenvalues above 1 are kept (Kaiser, 1960). These two criteria led to an optimal dimensional structure with two factors for each scale, explaining 66% of the variance for Food scale, 58% of the variance for PCP scale, and 58% of the variance for HP scale. All the items had good loading on one and only one factor, i.e. a loading superior to 0.4 (Boateng et al., 2018). No item was thus deleted based on this criterion. The same items loaded on factor 1 or factor 2 for each scale (Table 1). Factor 1 consisted of regular items and was therefore labeled *Natural Products* sub-scale (Cronbach α = .88 for Food, α = .85 for PCP, and α = .86 for HP). Factor 2 consisted of reversed items and was therefore labeled *Artificial Products* sub-scale (Cronbach α = .87 for Food, α = .85 for PCP, and α = .85 for HP). Moreover, intercorrelation between sub-scales was high for Food scale (r = -0.46), and quite low for PCP scale (r = -0.27) or HP scale (r = -0.32).

Table 1: Items and factors loading for each category of products

Factors and items	Factor loading		
	Food	PCP	HP
<i>Factor 1: Natural Products</i>	$\alpha=.88$	$\alpha=.85$	$\alpha=.86$
3. J'évite de ... contenant des colorants artificiels	.77	.72	.70
6. J'évite de ... ultra-transformés.	.80	.72	.75
8. Je préfère ... avec la liste d'ingrédients la plus courte possible.	.73	.72	.77
10. Je crois que ... naturels est meilleur pour la santé que de consommer des aliments ultra-transformés.	.83	.80	.79
11. Je pense que ... naturels est plus respectueux de l'environnement que de consommer des aliments ultra-transformés.	.84	.76	.77
12. Je crois que les ... naturels ont meilleur goût que les ... ultra-transformés.	.82	.69	.69
<i>Factor 2 : Artificial Products</i>	$\alpha=.87$	$\alpha=.85$	$\alpha=.85$
4. Ça m'est égal de ... qui contiennent des arômes artificiels.	.84	.81	.81
5. Ça m'est égal de ... qui contiennent des OGM (organismes génétiquement modifiés).	.84	.82	.79
13. Je fais plus confiance aux ... ultra-transformés qu'aux ... naturels.	.80	.76	.74
14. Ça ne me pose pas de problème éthique de ... ultra-transformés.	.79	.73	.79

For each item, the blank space is replaced by the name of the product category. For items 3, 4, 5, 6, 8, 10, 11 and 14, the blank is replaced by “consommer des aliments” for Food, by “utiliser des produits d'hygiène et de soin” for PCP, and by “utiliser des produits ménagers” for HP. For items 12 and 13, the blank is replaced by “aliments” for Food, by “produits d'hygiène et de soin” for PCP, and by “produits ménagers” for HP.

3. Principal study: Validation of psychometric scales

3.2 Method

3.2.1 Participants

The objective of this second study was to confirm with a new sample the psychometrics quality of the 10-items version of the scales. For this study, 408 participants were recruited via Qualtrics. A quota was applied on age, gender, and educational level to recruit a sample representative of the French population as in the preliminary study. The sample was composed of 53% of women (216 women for 192 men). The mean age of the sample was 47.9 ± 15.9 ; 10% were between 18 and 24 years old, 15% were between 25 and 34 y/o, 25% were between 35 and 49 y/o, 25% were between 50 and 64 y/o, and 24% were older than 65 y/o. For the educational level, 29% had under C grade or no diploma, 38% had high school level or equivalent, and 33% had a 2 years degree or more. Participants received a voucher of 4.5 euros

for their participation. To test temporal stability in the participants' responses, 198 of these participants were contacted again to fill out the questionnaire after one month.

3.2.2 Questionnaire structure

Participants were first informed of the study objectives and procedure. After giving written consent for their participation, they completed a demographic questionnaire. The rest of the survey was divided into three parts. In the first part, participants answered the 10-items version of the three scales (Food, PCP, HP). The order of presentation of the scales and sub-scales within a scale was randomized, as well as the order of items presentation within a sub-scale. As for the preliminary study, participants rated their level of agreement with the items on a 7-point Likert scale.

The second part of the survey aimed at assessing the validity of the scales, i.e. its ability to measure attitude toward naturalness, by testing the convergent and discriminant validity of our scales. To test convergent validity with *the Natural products* sub-scales, participants filled Roininen and colleagues (1999) sub-scale on naturalness. Discriminant validity for this sub-scale was assessed with Dickson-Spilman and colleagues (2011) sub-scale on chemicals and additives. This latter sub-scale on chemicals and additives also allowed for testing of convergent validity with *the Artificial products* sub-scales, while discriminant validity for this sub-scale was assessed with correlation with Roininen et al. (1999) sub-scale on naturalness. As the scales used for assessing convergent and discriminant validity were developed for food, we expected more positive or negative correlations with our food scale.

Predictive validity was set in the third part. To measure the predictive value of the *Natural products* sub-scales, participants evaluated their purchase frequency of organic food, organic personal care products, and organic household products (Michel et al., 2019). To measure the predictive value of the *Artificial products* sub-scales, they evaluated the purchase frequency of these products without a label in the supermarket for each product's category.

3.2.3 Data analysis

For each participant, we calculated an attitudinal score toward naturalness for each sub-scale and each scale as the sum of the participant's answers. The higher the score for *the Natural products* sub-scales, the more positive the attitude toward natural products. The higher the score for *the Artificial products* sub-scales, the more positive the attitude toward artificial products.

The dimensionality of the scales was assessed with confirmatory factor analysis (CFA), using maximum likelihood method. Scales' reliability was explored with Cronbach's alpha coefficient for internal reliability and Pearson-product moment correlation between the two sessions of the survey for temporal stability. Convergent validity, discriminant validity, and predictive value were assessed with Pearson correlation between attitudinal score and other scales' scores or purchase frequency. Then, ANOVAs were run to explore the effects of gender, age, educational level, and product category on attitude toward natural and artificial products. Analyses were conducted with R software, version 3.6.3. We set the alpha level at .05 for all statistical analyses.

3.3 Results

For *Natural products* sub-scales, attitude scores ranged from -18 to 18 for each category of products (M=10.6±6.1 for Food scale, M=7.5±5.8 for PCP scale, M=6.5±6.1 for HP scale), the higher the score the more positive the attitude toward natural products. For *Artificial products* sub-scales attitude scores ranged from -12 to 12 for each category of products (M=-5.7±4.9 for Food scale, M=-3.6±5.0 for PCP scale, and M=-2.7±5.3 for HP scale), the higher the score the more positive the attitude toward artificial products.

3.3.1 Dimensionality

As expected, the CFA showed that the 2-factors model with a correlation between factors better fit the data of this second study than a unidimensional model, for the three scales (Figure 1). Moreover, the analysis yielded a good fit of the data for PCP scale ($\chi^2(37)=136$, $p<.001$, CFI=.94, RMSEA=.08), but only acceptable fit indices for Food ($\chi^2(37)=275$, $p<.001$, CFI=.87, RMSEA=.13) and HP scales ($\chi^2(37)=319$, $p<.001$, CFI=.86, RMSEA=.14). As suggested by the EFA conducted on data from the previous study, items 3, 6, 8, 10, 11 and 12 loaded on the first latent factor named *Natural Products*, and items 4, 5, 13 and 14 loaded on the second latent factor named *Artificial Products* for each scale. All the items had good factor loading (range: .69 to .84), and factors were strongly negatively correlated ($r=-.63$, $p<.001$ for Food scales; $r=-0.61$, $p<.001$ for PCP scales; and $r=-0.62$, $p<.001$ for HP scales).

However, further analysis revealed that a 3-factors model would better fit the data for all the scales ($\chi^2(37)=136$, $p<.001$, CFI=.94, RMSEA=.08 for PCP scale, $\chi^2(37)=136$, $p<.001$, CFI=.94, RMSEA=.08 for Food scale, and $\chi^2(37)=136$, $p<.001$, CFI=.94, RMSEA=.08 for HP scale). In these models, items 3, 6, 8, and 12 would load on factor 1 (only items 3,6 and 8 Food

scale), items 10 and 11 would load on factors 2 (and item 12 on the Food scale), and items 4, 5, 13 and 14 would still load on the same factor named *Artificial Products*. This 3-factors structure has poor theoretical meaning and is probably due to differences and the item wording. Indeed, 3 to 8 items have an affirmative structure (e.g. “*I avoid consuming foods that have artificial colors*”.) while items 10 to 14 have a comparative structure (e.g. “*I believe consuming natural foods is healthier than consuming highly processed foods*”). For this reason, and despite the better fit of the model, we favored the 2-factors models depicted in figure 1.

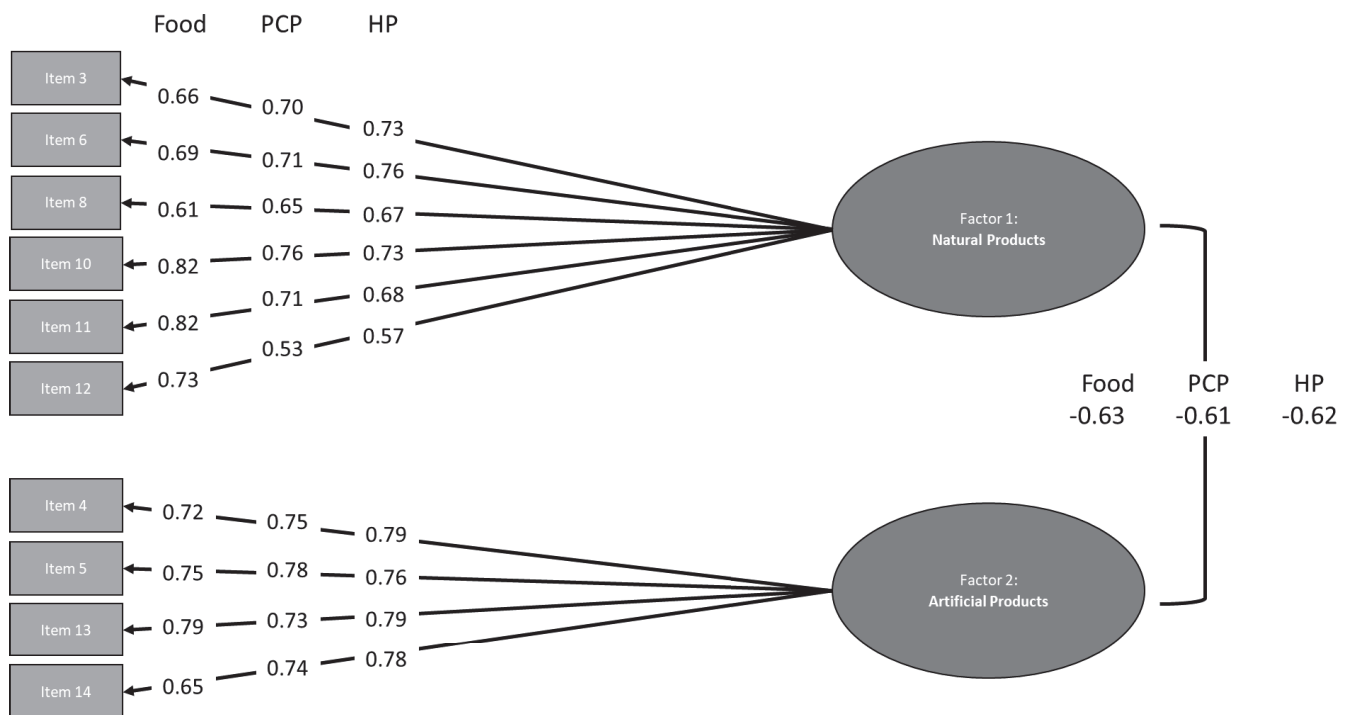


Figure 1: Path diagram yielded by the confirmatory factor analysis for each scale

3.3.2 Internal consistency and test-retest reliability

Internal consistency was satisfactory for all sub-scales of all scales: for *Natural products* sub-scales, $\alpha=.86$ for Food, $\alpha=.83$ for PCP, and $\alpha=.84$ for HP scale, while for *Artificial Products* sub-scales, $\alpha=.82$ for Food, $\alpha=.84$ for PCP, $\alpha=.86$ for HP scale. These results suggested good internal consistency of the scales. Moreover, temporal reliability was acceptable, as scores at the two administrations of the scales were correlated for all the sub-scales (Table 3). However, paired t-test yielded significant differences between the two administrations for the Natural Household Products scale ($t(196)=2.5, p=.01$) and Natural Personal Care Products ($t(196)=2.5,$

p=.01). These results suggest a slight temporal variability in the participants' response to the scale.

Table 3: Test-retest reliability of the PNS scales (n=198)

Scale and sub-scale	Time 1		Time 2		Correlation coefficient
	Mean	Standard deviation	Mean	Standard deviation	
<i>Natural Products</i>					
Food	12.9	6.23	12.6	5.87	.63 ***
Personal Care Products	16.3	5.86	15.4	6.33	.65 ***
Household Products	17.1	5.71	16.1	6.71	.57 ***
<i>Artificial Products</i>					
Food	22.3	4.53	22.2	5.23	.65 ***
Personal Care Products	19.9	4.87	20.2	5.32	.54 ***
Household Products	18.8	4.95	19.2	5.64	.53 ***

Pearson's product-moment correlation test, *** $p < .001$ ** $p < .01$ * $p < .05$ # $p > .05$

3.3.3 Convergent and discriminant validity

To test the convergent validity of the *Natural Products* sub-scales, we analyzed the correlation of participants' responses to these sub-scales with participants' responses to the Roininen (1999) scale on Naturalness. Results showed that *Natural Products* sub-scales were positively correlated with the Roininen et al. scale (1999) on naturalness ($r = .66$, $P < .001$ for Food scale, $r = .53$ $P < .001$ for PCP scale, and $r = .47$ $P < .001$ for HP). Roininen et al. scale (1999) investigating attitude toward natural food was more correlated with *Natural foods* sub-scales than with the other product categories. Then, the correlation of participants' responses to the Dickson-Spilman and colleagues (2011) sub-scales on chemicals and additives was assessed. Results revealed that *Natural Products* sub-scales were positively correlated with the negative attitude toward chemicals sub-scale ($r = .53$ for Food, $r = .61$, for PCP, and $r = .51$ for HP, all $ps < .001$), but they were negatively correlated with the positive attitude toward chemicals sub-scale ($r = -0.37$ for Food, $r = -0.28$ for PCP, and $r = -0.27$ for HP, all $ps < .001$).

For *Artificial Products* sub-scales, analysis of correlation revealed a convergent validity with a positive attitude toward chemicals sub-scale (Dickson-Spillmann et al., 2011), with $r = .47$ for Food, $r = .46$ for PCP, and $r = .47$ for HP, all $ps < .001$. Correlations with the negative attitude toward chemicals sub-scale (Dickson-Spillmann et al., 2011) were negative for all the categories of products: $r = -0.38$ for Food, $r = -0.38$ for PCP, and $r = -0.37$ for HP scale, all $ps < .001$.

Correlations were also negative with Roininen et al. scale (1999) on naturalness ($r=-0.65$ for Food, $r=-0.57$ for PCP, and $r=-0.59$ for HP scale, all $ps<.001$).

3.3.4 Predictive value

To test the predictive value of our scales, we investigated the correlation between our scales and the real-life consumption of participants. The predictive value of *Natural Products* sub-scales was estimated by looking at the correlations of these sub-scales with the frequency of purchase of organic products, for each category of products. For *Artificial products* sub-scales, we analyzed the correlation of these sub-scales with the consumption of standard products in supermarkets. Table 4 summarized the results. Analysis of correlation yielded a good predictive value of *Natural Products* sub-scales, as the sub-scales were positively correlated with the frequency of purchase of the related organic products ($r=.31$ for Food, $r=.43$ for PCP, and $r=.40$ for HP, all $ps<.001$). Sub-scales were also correlated between the scales, and also with the frequency of consumption of organic products for the other categories of products. However, the correlations were the highest within a category of product (e.g. *Natural Products* sub-scale of the PCP scale was more highly correlated with the frequency of consumption of organic PCP than with the frequency of consumption of organic Food). On the other side, *Natural Products* sub-scales were not correlated with the frequency of purchase of standard products in supermarkets ($r=-0.04$, $p=.37$ for Food, $r=-0.06$, $p=.27$ for PCP, and $r=-0.06$, $p=.26$ for HP).

The frequency of purchase of standard products in supermarkets was slightly positively correlated with *Artificial Products* sub-scales, for the Food scale ($r=.15$, $p=.003$), PCP scale ($r=.14$, $p=.004$), and HP scale ($r=.12$, $p=.01$). *Artificial Products* sub-scales were negatively correlated with the frequency of purchase of organic products ($r=-0.23$ for Food, $r=-0.27$ for PCP, and $r=-0.26$ for HP, all $ps<.001$).

Table 4: Correlation between frequency of purchase and attitudinal scales

Scale and sub-scale	Frequency of purchase of organics products for...			Frequency of purchase of standards product in the supermarket for...		
	Food	PCP	HP	Food	PCP	HP
<i>Natural Products</i>						
Food	.31 ***	.27 ***	.30 ***	-.04	-.10	-.04
Personal Care Products	.31 ***	.43 ***	.40 ***	.01	-.06	-.02
Household Products	.27 ***	.36 ***	.40 ***	-.03	-.08	-.06
<i>Artificial Products</i>						
Food	-.23 ***	-.20 ***	-.20 ***	.15 **	.15 **	.13 *
Personal Care Products	-.18 ***	-.27 ***	-.23 ***	.11 *	.14 **	.08
Household Products	-.17 ***	-.27 ***	-.26 ***	.15 **	.17 ***	.12 *

Pearson's product-moment correlation test, *** $p < .001$ ** $p < .01$ * $p < .05$

3.3.5 Variation of attitude toward naturalness according to gender, age, educational level, and products categories

The variability in the attitudinal score of our scales reflects the ability of the scale to capture inter-individual variability in attitude toward natural products. We then examined the extent to which demographic factors explain this variability. The effect of gender, age, and educational level was analyzed with an Anova for each sub-scales and product category. For the *Natural products* sub-scale, the results showed a significant effect of gender for the three categories of products ($F(1)=4.58$, $p=.03$ for Food; $F(1)=14.2$, $p<.001$ for PCP; and $F(1)=14.8$, $p<.001$ for HP), as women had on average a more positive attitude toward natural products than men (figure 2A). The effect of educational level and age were not significant (figure 2B and 2C). For the *Artificial products* sub-scales, results showed an effect of gender ($F(1)=4.8$, $p=.03$ for Food; $F(1)=6.3$, $p=.01$ for PCP; and $F(1)=9.2$, $p=.003$ for HP), as women had a more negative attitude toward artificial products than men for the three categories of products (figure 3A). The model also yields an effect of age ($F(1)=11.5$, $p<.001$ for Food, $F(1)=7.6$, $p=.006$ for PCP, and $F(1)=13.0$, $p<.001$ for HP), the younger the participants the less negative the attitude toward artificial products for food and household products (figure 3B). The effect of the educational level was not significant (figure 3C).

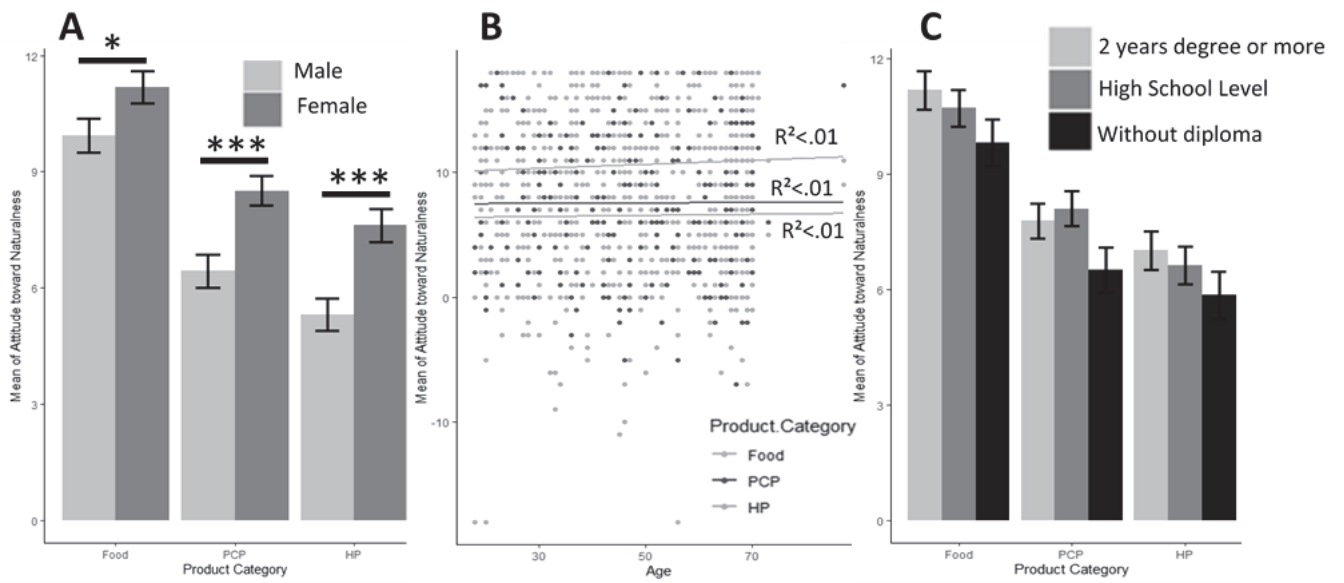


Figure 2: Attitudinal scores toward *Natural products* depending on the category of product and gender (A), correlation between attitudinal scores toward natural products and age (B), and attitudinal scores toward natural products depending on the category of product and educational level (C), *** $p < .001$ ** $p < .01$ * $p < .05$

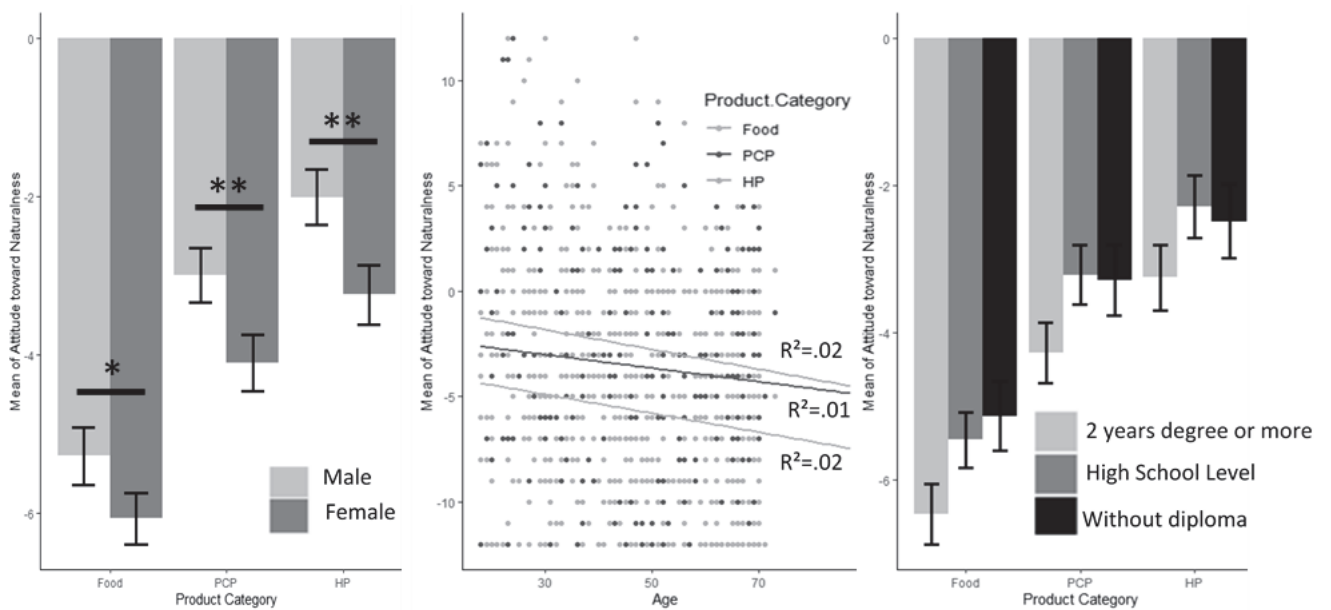


Figure 3: Attitudinal scores toward *Artificial products* depending on the category of product and gender (A), correlation between attitudinal scores toward artificial products and age (B), and attitudinal scores toward artificial products depending on the category of product and educational level (C), *** $p < .001$ ** $p < .01$ * $p < .05$

Attitudes toward *Natural Products* were also compared across product categories using a linear mixed model. The attitudinal score was set as the dependent variable, the product categories as the predictor, and the participants as a random factor. Results yielded a significant effect of product categories ($\chi^2(2)=276.0$, $p<.001$). Post-hoc tests revealed that attitude was more positive toward natural food than toward natural PCP and natural HP, and attitude was more positive toward natural PCP than toward natural HP (figure 4A). Attitudes toward *Artificial Products* were also compared following the same model. The effect of the category of product was significant ($\chi^2(2)=211.5$, $p<.001$). Post-hoc tests revealed that attitude toward artificial food was more negative than toward artificial PCP and artificial HP, and attitude toward artificial PCP was more negative than toward artificial HP (figure 4B).

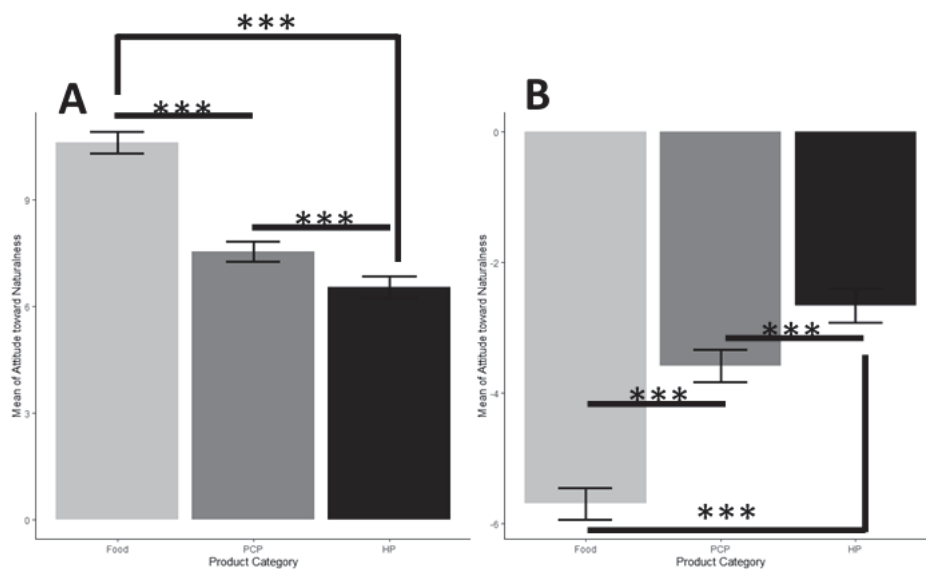


Figure 4: Attitudinal scores depending on the category of product toward Natural products (A), and Artificial products (B), *** $p<.001$ ** $p<.01$ * $p<.05$

4. General discussion

Our first objective was to present the validation of a new attitudinal scale measuring attitude toward natural food developed from a review of naturalness meanings and dimensions. The development procedure of the scale leads to a final version with 10 items. These items are divided into two sub-scales, one assessing the attitude toward *Natural Food*, and the other assessing the attitude toward *Artificial Food*. The structure and items are identical for the Personal care products and the Household products scales. Evaluation of the final version of

the scales (study 2) confirmed the bi-dimensional structure of the scale and yielded satisfactory psychometric properties for the three scales. Only the test-retest reliability of the *Natural Products* sub-scale for PCP and HP scales was slightly above standard indices and would deserve further investigations.

Moreover, all three scales have shown their ability to capture inter-individual variability in attitude toward naturalness. Analysis of the differences in attitude depending on demographic factors showed that gender and age variables explained some part of this inter-individual variability. These results are in line with previous research that found differences in attitude toward naturalness between genders, the women according to higher importance to naturalness than men (Step toe et al., 1995; Roininen et al., 1999; Bäckstrom et al., 2004, see Romàn et al., 2017 for a review). Moreover, most of the studies investigating demographic factors influencing attitude toward naturalness found also an effect of age, the younger participants having a less positive attitude toward naturalness than older participants (Step toe et al., 1995; Roininen et al., 1999; Renner et al., 2012, see Roman et al., 2017 for a review). However, in our results, the age effect was significant only on attitude toward artificial products, as the younger participants had a less negative attitude toward artificial products than older participants did. As previous studies did not distinguish these two dimensions, the previous effect observed might be underpinned by differences in attitude toward artificial products rather than natural products. Moreover, in line with Step toe and Wardle (1999), and contrariwise to Kornelis and colleagues (2010), the effect of education on attitude toward naturalness was not significant in our results (Kornelis et al., 2010; Step toe & Wardle, 1999). Further investigations might use our newly developed scales to explore the effects of other demographical or psychological factors on attitude toward naturalness.

Moreover, the development and validation process raises new insights about natural products' meaning and attitudinal scales properties.

Dimensional structure

First, the analysis of dimensional structure raises many questions. The bi-dimensional structure of the scales suggests that natural products and artificial products are two distinct dimensions rather than two poles of the same dimension. Indeed, with this latter option, the factorial analysis should have led to a unidimensional structure with negative loading for items targeting artificial products rather than a bi-dimensional structure. This distinction between the two

constructs addresses the complex question of the opposite term of “natural”. We decided to avoid the term artificial, as this word is vague and has little meaning for food. We thus looked for the best opposite for each category of products and chose “highly processed” for food and “synthetic” for PCP and HP. The strong correlation between the two factors in each scale suggested a close meaning between natural products and the opposite term we chose, but not a strict opposition.

However, the wording rather than the meaning of the items could also partly explain this bi-dimensional structure. Indeed, factorial analysis in study 2 suggested that a 3-factors model best fitted the data. The model had affirmative items targeting Natural products in factor 1, comparative items targeting Natural products in factor 2, and reversed items targeting Artificial products in factor 3. This result illustrates the importance of syntax and wording for factorial analysis. Even slight heterogeneity in the structure of the item (affirmative or comparative structure) can lead to different response strategies, and thus to a multifactorial structure although the latent construct is in fact the same (Weijters & Baumgartner, 2012).

Items reduction and naturalness meaning

A second point worth mentioning is the issue of tangential construct and deleted items. During the development phase of the scales, items 7 and 9, investigating both the issue of homemade versus industrial products, were deleted because they were poorly correlated with the other items. This result suggests that the homemade/factory-made dimension is distinct from the naturalness dimension. However, the correlation was smaller for the PCP scale. As homemade PCP is less common than homemade foods, this difference could also be explained by the fact that it means little for this category of products but is part of naturalness meaning for the others. As the homemade trend is growing, further studies on this point could lead to different perceptions of the relationship between these dimensions in near future. Similarly, the use of feral plants for food is not uncommon, but it is for PCP or HP. This difference might explain why some participants found it difficult to answer the items about the use of feral plants in inedible products. Therefore, the relation between wilderness, naturalness, and health perception would deserve further investigation, but restrained to the food domain.

These examples illustrate the difficulty to keep scales homogeneous between the categories of products. Indeed, our second objective was to develop and validate an attitudinal scale to measure attitudes toward natural inedible products and to compare attitudes toward natural

products between categories. The developed items were identical between scales, except for the product category name. While psychometric parameters, like the dimensional structure of the scales, were quite close between scales, the constraint of homogeneity led to the deletion of items for all the scales although they were problematic only for a category of products (like items 7 and 9). This constraint also prevents the inclusion of items targeting aspects of naturalness that would be specific to a category of products, e.g. some ingredients used only in food like hormones. Moreover, this constraint was necessary to maintain the equivalence of the measured construct between scales and allows for comparisons of attitudinal scores.

Comparison of attitudes toward naturalness between categories of product

Following our first hypothesis, attitude toward natural foods was expected to be more positive than attitude toward inedible products. Our results provide evidence supporting this hypothesis, as the average attitude toward natural foods was indeed more positive than the average attitude toward natural inedible products. In addition, two non-edible categories were also chosen to modulate the distance between the product and the users' bodies, with one product with proximal use (PCP put on the skin), and the other with distal use (HP spreading in the air, or used with an intermediate such as a sponge or mop). Even if the difference is smaller between these categories than between food and the two other categories of products, we observed that, on average, attitude toward natural PCP was more positive than attitude toward natural HP. These results suggest that, the closer the product is to the body, the more positive the attitude toward naturalness is. This effect might be mediated by the perception of contagion and health risk. The analysis of the interrelation between the distance of the body, contagion and health risk, and attitude toward naturalness would be a future perspective of this work. However, environmental concern which is also a driver of the demand for natural products (Roman et al.), could potentially explain some of the interindividual variability in the attitudes toward natural products and should also be taken into account.

5. Conclusion

The present paper aimed at presenting the validation of three new scales measuring attitude toward naturalness, for three different categories of products. The first motivation for the development of these new scales was to extend and complete with recent results the scope of dimensions included in the naturalness definition. Some of the added dimensions were left apart during the development process. At the end of the development procedure, and compared to

Michel and colleagues scale (2019), beliefs about the attributes of natural products were included in our scale. Moreover, as research about naturalness keeps moving, new dimensions such as homemade production might appear in the future as related to naturalness and thus be included in the measurement of attitude toward naturalness. This work is not complete but should be expanded as new knowledge about naturalness is acquired.

Our second objective was to compare attitudes toward naturalness between different categories of products. In line with our hypothesis, our result showed that attitude toward naturalness is more positive for food than for inedible products, and more positive for personal care products than for household products. Future investigations could bring new elements to understand the factors underlying these differences, especially about the attitude and beliefs toward health and the environment.

The last perspective concerns the link between attitude and perception of naturalness. Indeed, Michel and colleagues (2019) found that the participants with the most positive attitude toward natural food also perceived canned ravioli as less natural than other participants. Our scales provide new tools to investigate this relation in a more general domain than food.

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Interim Summary Chapter 3

The need to develop new attitudinal scales was based on two observations. The first was that existing scales were incomplete for measuring naturalness because they did not take into account all the factors that modulate naturalness. The second observation was that previously validated scales were limited to the food domain. In addition, in developing new tools to capture inter-individual variability in attitudes toward naturalness for three product categories, the purpose was to compare attitudes across product categories. In addition, the development of these scales was also intended to develop tools to study the relationship between attitude toward naturalness and perception of naturalness in future research.

The results show that the psychometric properties of our scales meet the gold standard for scale development. In addition, our scales captured inter-individual variability, highlighting their relevance for measuring attitudes. Furthermore, we observed that attitudes were more positive toward natural foods than toward non-natural foods. Further studies could attempt to investigate the dimensions underlying these differences in attitude, including exploring the relationship between attitude and health and environmental expectations. Finally, this study has allowed us to develop tools that can be used in our future studies to investigate the link between attitude and perceived naturalness.

In this first chapter, we have explored the question of interindividual variability in the attitude toward naturalness. In the next experimental chapters, we will study more specifically the factors modulating the perception of the naturalness of odors, keeping in mind the question of inter-individual variability, and the fact that this variability can be explained by the variability of attitudes towards naturalness.

Chapter 4- Study of the factors modulating naturalness of smells

After seeking to clarify the concept of naturalness and addressing the issue of interindividual variability, we further explored in this chapter the factors that modulate the perceived naturalness of odors. As few studies have addressed this issue, we divided our research into several successive research steps.

First, in a first exploratory study, we investigated consumers' expectations in terms of sensory characteristics of natural products, and the effect of a contextual element on these expectations, the product category. Considering that a source of variability also comes from culture, this research was conducted with two samples from different cultures (France and the United States). Then, with the results of our first study, we conducted a second study to confirm our observations when evaluating olfactory stimuli. In this study, 29 participants evaluated the naturalness of 33 odors and their pleasantness, edibility, familiarity, intensity and arousal, and identified them.

This second experimental chapter therefore provides elements related to our hypotheses 1, 2, 3 and 4 through two different methodological approaches.

Study 2 – Olfactory attributes and colors associated with naturalness

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Olfactory attributes and colors associated with naturalness

Morgane Dantec, Helene Allain, Nathalie Yvert, Julia Sigrist, Moustafa Bensafi, Jeremie Lafraire

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Olfactory attributes and colors associated with naturalness

Dantec M^{1,2,3§}, Allain H¹, Yvert N¹, Sigrist J¹, Bensafi M³, Lafraire J²,

¹ Marketing, Sensory & Consumer Research, V. Mane Fils, Le Bar sur Loup, France

² Institute Paul Bocuse Research Center, Ecully, France

³ Lyon Neuroscience Research Center, CNRS-INSERM-University of Lyon, France

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[§] Corresponding author

Centre de Recherche de l'Institut Paul Bocuse

Château du Vivier

1A Chemin de Calabert

69130 Ecully - FRANCE

Email: morgane.dantec@institutpaulbocuse.com

Highlights

- Specific olfactory properties like freshness and lightness were founded to be associated with natural odor
- Green, white and yellow were reliably associated with natural products
- Culture and product categories appeared to modulate associations between colors and natural products and expected intensity of natural products' odor and color

Abstract

In developed countries, naturalness is an important food attribute for the majority of consumers. However, the relation between natural products and their sensory properties are still poorly understood, and only few studies explored the olfactory attributes and colors associated with naturalness. In the present study, American and French participants were asked to associate attributes with natural and unnatural odors, and colors with natural products. Results showed that freshness was more often associated with natural odors, while green, white and yellow were the colors associated with natural products. However, our results also underlines disparities between countries and categories of products, as American participants expected higher intensity of natural products' color and odor, and choose less often white than French respondents. Brown, green, and orange were more associated with food, while blue and white were chosen more often for non-foods products. Taken together, these findings bring new insights on consumers' expectations and consumers' associations between olfactory properties, colors and natural products.

Keywords: Naturalness, sensory properties, odors, colors

1. Introduction

There is a growing demand for natural products, in food and non-food domain. Despite socio-demographic variability, naturalness features today among main expectations of a majority of consumers. Women, old consumers, and consumers with high income give greater importance to food naturalness (Bäckström et al., 2004; Olbrich et al., 2015; Roininen et al., 1999; Steptoe et al., 1995). Natural products are expected to have positive attributes: to be fresh, to be tasty, to be environmentally friendly, and to be healthy (Román et al., 2017). Moreover, preferences for “natural” exceed instrumental motivations (i.e. material or functional superiority), and is also based on ideational motivations, which means “the desirability of natural per se (for moral or ideational/aesthetic reasons)” (Rozin et al., 2004). To answer this demand, more and more products are presented with “natural” labels. However, no legal definition of a “natural product” exists in France, nor in the US, and these labels cover a variety of realities. As naturalness remains a vague concept, there is a need to better understand consumers’ definition and expectations of natural products.

What is a natural product? There is no clear consensus to answer this complex question. “Natural kinds”, which are the “naturally occurring objects”, are often opposed to “artifacts” which are made by humans. These categories have different specificities. The “naturally occurring objects” imply a particular internal structure (genetic or chemical), whereas artifacts imply a particular function (Gelman, 1988). In light of this definition, we might postulate that transformations changing the particular internal structure alter the most the naturalness of a natural object. In the food domain, Paul Rozin (2004) has defined natural food as “one that had not been changed in any significant way by contact with humans. It could have been picked or transported, but it was chemically identical to the same item in its natural place”. He opposed natural food to processed food, defined as “one that had been grown with fertilizers or pesticides and that might contain additives or preservatives to enhance its taste” (Rozin et al., 2004, p. 148). The neuropsychologist Raffaella Rumiati introduced a subdivision in the food category into “natural (i.e., fruit/vegetables) and manufactured (i.e., “food that underwent some kind of organoleptic transformation”) (Rumiati & Foroni, 2016,p.104). Roman and colleagues reviewed the studies conducted to measure how naturalness is important for consumers in their food choices. They observed that a majority of studies relied on three criteria when it comes to assess products naturalness: “how the food is grown” (organic or local), “how the food is produced” (for example without additives or artificial colors, produced with traditional

methods), and the properties often attributed to natural foods (e.g. ecofriendly, healthy, tasty or fresh) (Román et al., 2017).

However, it has been argued that none of the above mentioned criteria might be used as a clear cut-off point between natural kind and artifact, and several authors raised the issue of the relativity of naturalness (Gelman, 1988; Lepiller, 2016). For example, Susan Gelman highlighted that, domesticate animals or cultivated plants like wheat or corn, are borderline cases, as they do not belong to the artefacts, but they have been modified by human selection. Considering these borderline cases, the author proposed that “there is probably a continuum rather than a strict dichotomy between natural kinds and artifacts” (Gelman, 1988, p.69). The degree of naturalness for a product would then be its particular place on this continuum, and represents its distance from its naturally occurring state. The more the product has been changed in its essence by human interventions, the lower its naturalness would be.

Moreover, human actions do not all have the same effect on naturalness. Indeed, Rozin and his colleagues (2005) showed that, for consumers, chemical transformations, like adding fat, affect naturalness more than physical ones, like freezing (Rozin, 2005). Their results also underlined that 1) the contagion by unnatural entities (e.g. synthetized purified minerals) strongly affects the naturalness of a product, 2) the history of an entity’s manufacturing process has a higher effect than its actual content to determine its naturalness, as significant changes in genotype and phenotype due to generations of domestication are perceived as less destructive of naturalness than adding a single gene by genetic engineering and 3) mixing natural entities (e.g. mixing spring water) marginally affects naturalness. In line with Rozin’s study, Evans and colleagues (2010) suggested that the more the food was processed (i.e. “physical or chemical changes to the food or ingredients”) the less it was perceived as natural (Evans et al., 2010). Abouab and Gomez (2015) showed that the production mode (hand-made vs. machine-made) played a role in the naturalness evaluation. The name of the ingredients is also of interest in the evaluation of naturalness. Indeed, E-numbers or chemical names, like E100 for curcumin, were evaluated as less natural than their equivalents with common names (Chambers et al., 2018; Evans et al., 2010; Murley & Chambers, 2019; Siegrist & Sütterlin, 2017).

Sensory characteristics of packaging also influence the perception of products’ naturalness. Indeed, beyond the functions of protection and transportation, the graphic and structural properties (color, pictures, shape, type of materials) of the packaging can have an impact on the consumers’ expectation about the product inside (Ampuero & Vila, 2006). For example, the

color of the package (orange vs white) influences the expected freshness and naturalness of fruit juice, as white background on the bottle is perceived as more natural, purer, fresher, and is more appreciated than the orange one (Deliza et al., 2003). In a study conducted in 2013, Labbe and his colleagues observed a positive correlation between roughness and suppleness of packaging with expected naturalness of the product, and a negative correlation between noise intensity (i.e. “loudness of the noise when the fingertips slide on the material’s surface”) and expected naturalness (Labbe et al., 2013). However, the literature on sensory properties of natural products is small, and does not cover olfactory attributes.

The first objective of the present study was to explore which olfactory attributes and which colors were associated with natural products. These two modalities are linked with flavor evaluation, odor being one component of flavor, and color being a relevant cue about the flavor of a product (Garber et al., 2000; Spence, 2016). Moreover, as they both are sensory cues which can be experienced before product consumption, they can have a great influence on consumers’ expectations prior to consumption. To achieve this aim, we investigated the semantics association between odors and naturalness, and colors associations with natural products. As some studies highlighted the role of intensity in naturalness’ perception and cross-modal associations (Spence, 2011; Zellner, 2013; Zellner et al., 1991) we also raised the question of the expected intensity for color and odor of natural products.

The second objective of the present study was to explore how these associations were modulated by culture and product category. Indeed, culture is a prominent factor in odors’ perception and cross-modal association (Ferdenzi et al., 2016; Levitan et al., 2014). Moreover, effect of context on perception, seen as effect of variables like physical, social and temporal environments, or also effect of intrinsic properties of the product, or effect of individual characteristics have been extensively documented, especially for food (see (Dacremont & Sester, 2019) for a review). In the case of naturalness, Lunardo and Saintives (2013) showed that the point of purchase affect the perception of naturalness, as the same chocolate cookie picture was perceived as more natural when presented with traditional market context rather than supermarket context (Lunardo & Saintives, 2013). Moreover, results from Michel et al. (2019) underline that importance given to food naturalness varies according to the product category. Participants’ preferences for organic food was higher for unprocessed foods than for processed foods. However, impact of the category of product on perception and expectation of

naturalness has been little studied, even though they are subject to very different regulations and standards of production.

2. Method

2.1 Participants

The study consisted in a survey conducted via an online panel of French and North-American participants. These countries were chosen for a cultural comparison, as they are closed in terms of organization of consumer goods markets (production with manufacturers, supermarket as purchase point, etc.) and classification of consumer goods products (Food, personal care products and household products represent different categories with different functions). Definition of naturalness and attitude toward naturalness are also close between these countries (Rozin et al., 2012). Cultural differences have however been highlighted between these countries about attitude toward some products, like GMO (Rozin et al., 2012). Moreover, consumer goods and food market differ to some extent between these countries, and cultural differences have been underlined on the associations between colors and odors for example (Levitan et al., 2014). The questionnaire was developed in French, and then translated into English. French participants were recruited via Mane online Proprietary Panel, and American participants were recruited via a global consumer panel company named Toluna. Questionnaire was sent to both panels in January 2020. Our final sample consisted of 838 French participants and 505 Americans. For the French sample, 62% were women, 13% were in the 18-34 age group, 34% in the 35-49 age group, and 53% were in the 50 years old and over age group. For the American sample, 51% were women, and 35% were in the 18-34 age group, 30% were in the 35-49 age group, and 35% were in the 50 years old and over age group. To adjust these samples to the target population structure, we applied a population weighting adjustment based on age and gender (see data analysis part for more details).

2.2 Questionnaire and data collection

The questionnaire was divided into four sections. The first part was dedicated to standard demographics (age, gender and region). Then, in a second part, in order to better understand the consumers' definition and perception of natural odors, participants were asked to give, at least one and up to three adjectives associated with a natural odor. The same question was asked for unnatural odors. In the third part of the questionnaire, participants rated the expected intensity of natural products' odors and colors on an 8-points visual analog scale, from 1-Very weak to

8-Very intense for odors and from 1-Very pale to 8-Very vibrant for colors. Since we also aimed at investigating the effect of the product category on expected intensity, participants were asked to rate the expected intensity of natural products' colors for three categories of products: natural food, natural personal care products, and natural household products. For odors, they rated the expected intensity of natural odors for these categories and for natural strawberry as well. Natural food category gathers a wide diversity of products, so we investigated if an unprocessed food - a fruit - would be perceived differently from the general food category.

The goal of the fourth part was to explore the associations between natural products and colors. Here, participants had to choose on a color palette with different hues (white, yellow, orange, pink-red, purple, blue, green, brown, grey and black) all the colors that best matched natural foods, natural personal care products, and natural household products. General categories of products, like food, cover a large amount of different products and thus does not allow to dissociate associations mediated by naturalness from those mediated by typicality. Indeed, literature on cross-modal associations, between odors and colors for example, underlined the importance of typicality in mediating associations (Spence, 2020). To tackle this issue, participants had then to choose the color they considered to be natural for a strawberry (“Among the following colors, which ones do you consider NATURAL for a STRAWBERRY (as opposed to ARTIFICIAL)?”), and the color they considered to be artificial for a strawberry. We chose these four categories for two reasons: i) to investigate if participants would be able to associate colors with very general categories (food, personal care products, and household products), ii) to explore if typicality would become a more salient dimension in the association between colors and natural products as the specificity of the category increases. As hue and lightness have been shown to be salient dimensions in the cross-modals associations with colors (Kemp & Gilbert, 1997; Spence, 2011), we offered them a 2D color palette varying in terms of hue (Yellow, Orange, Red, Pink, Green, Purple) and lightness (light, bright and dark for each hue) leading to 18 different possible choices.

Data were collected anonymously, and collection and storage of data respected rules and regulations of GDPR and CNIL. The study conformed to the Declaration of Helsinki.

2.3 Data analysis

Text corpus from semantic associations between naturalness and odors was analyzed with Sphinx software. To study semantic associations rather than inflectional forms, lemmatization

was conducted on the corpus (Gries, 2011). We studied which words had the most occurrences, and analyzed associations between naturalness and odors following three thematic dimensions: emotional valence, sensory attributes, and synonym of “being natural” or “being artificial” for odor. For questions about intensity, associations with colors, analyses were performed in R and significance level was set at $\alpha = 0.05$. Our samples did not have the same demographic structure as original populations (French and American population). Thus, we applied a population weighting adjustment, to adjust our sample to original population by a multiplying factor based on age and gender (Kalton & Flores-Cervantes, 2003). We analyzed adjusted sample data. Participants rated expected intensity of odors and colors of each product category. To look for differences between product categories within each participant, we analyzed data from intensity ratings with an ANOVA including product category as a within factor, and country, age and gender as between factors. Then we conducted a post hoc test corrected for multiple comparisons (Bonferroni). For questions on associations between colors and natural products or strawberry, we used χ^2 test and post hoc Bonferroni corrected χ^2 to test particular associations between colors and products, and also effect of culture and categories of products on these associations.

3. Results

3.1 Associations between colors and natural products

We tested whether the observed associations between colors and natural products were nonrandom with a χ^2 test between the participants' choices of colors (number of times each color was chosen for a given product category and a given country) and the random equal distribution (i.e. 10% of choices for each color), for each categories of products and both countries. Results show that for all product categories and in both countries, distributions of choices were nonrandom (all $p < .05$, see Table 1, column Randomness Test for details), which means that particular colors were associated with natural products. To capture particular associations between colors and natural products, we conducted post hoc χ^2 comparisons with Bonferroni correction ($\alpha = .005$) to compare theoretical random choices with participants choices of colors, for each color in each condition (3 product categories X 2 countries). For both countries, post hoc χ^2 with Bonferroni correction showed that the two non-food natural product categories, personal care products and household products, were matched with green, yellow and white. Food was matched with green, yellow and orange in the American sample,

and with green, yellow, white and orange in the French sample (all $p < .005$) (see Table 1, column matched color for details).

Table 1: Matches between colors and natural products, according to the category of product and the country

Category of product	Country	Randomness test	Matched color	Un-matched color
Food	US	$\chi^2(9)=263.88$, $p < .001$	Green (22%), Orange (16%), Yellow (16%)	Black (2%), Blue (6%), Grey (2%), Purple (7%)
	France	$\chi^2(9)=572.87$, $p < .001$	Green (20%), Yellow (19%), White (19%), Orange (15%)	Black (1%), Blue (4%), Grey (2%), Purple (4%)
Personal Care	US	$\chi^2(9)=188.7$, $p < .001$	White (20%), Green (17%), Yellow (15%)	Black (2%), Grey (5%), Pink-Red (5%), Purple (5%)
	France	$\chi^2(9)=496.86$, $p < .001$	White (25%), Yellow (20%), Green (14%)	Black (1%), Brown (4%), Grey (2%), Pink-Red (7%), Purple (5%)
Household Product	US	$\chi^2(9)=200.33$, $p < .001$	Green (18%), Yellow (18%), White (16%)	Black (2%), Brown (6%), Grey (4%), Pink-Red (6%), Purple (6%)
	France	$\chi^2(9)=477.32$, $p < .001$	White (23%), Yellow (19%), Green (17%)	Black (1%), Brown (3%), Grey (3%), Pink-Red (7%), Purple (6%)

Results of χ^2 analysis to test the non-randomness of choices of colors for each product category and each country are displayed in column "Randomness Test". A significant p ($p < .05$) implies that the distribution of participants' color choices were not homogeneous with equal distribution, i.e. choices were not equal between colors. Matched colors are those that were significantly selected more than 10% of the time (post hoc comparisons with Bonferroni correction $\alpha = .005$), while un-matched colors are those that were significantly selected less than 10% of the time (post hoc comparisons with Bonferroni correction $\alpha = .005$).

Moreover, for the three categories of products, χ^2 test showed a non-homogeneity in the distribution of participants' color choices between countries: food ($\chi^2(9)= 110.33$, $p < .001$), Personal Care products ($\chi^2(9)= 69.952$, $p < .001$), Household Products ($\chi^2(9)= 54.157$, $p < .001$). Indeed, for food, American respondents selected brown and purple more often than French respondents (all $p < .005$) and we observed a trend for blue ($p = .0052$ before correction), while French respondents selected more often white than American respondents did ($p < .005$), and we observed a trend for yellow ($p = .01$ before correction). For Personal care products, American respondents chose more often blue, brown, grey (all $p < .005$) and less often yellow and white ($p = .002$) than French respondents. For household products, American respondents selected more often brown ($p < .005$), and less often white ($p < .005$) than the French respondents (see figure 1 for details).

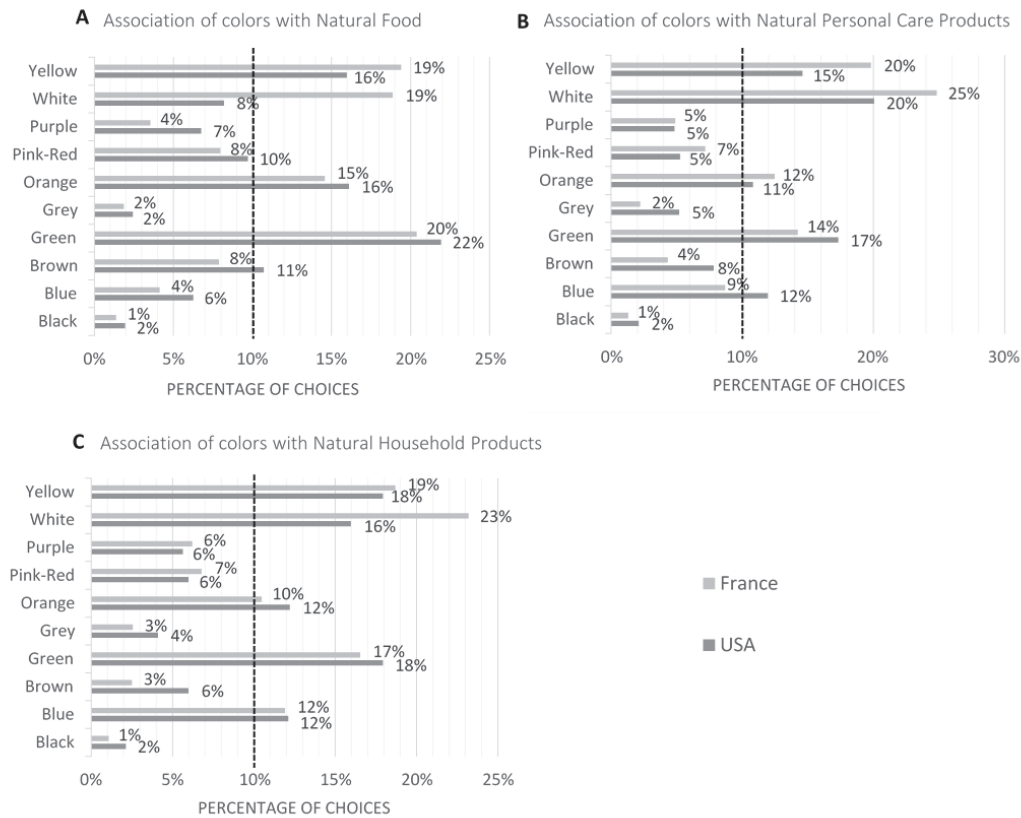


Figure 1: Association between colors and natural food (A), natural personal care products (B), and natural household products (C) depending on the country of the panel. Horizontal bars represent the percentage of choices of each colors for each panel, i.e. the number of time each color was associated with a natural product, and the black dotted line represent the chance level.

Results also showed disparities between categories of product. Indeed, distributions of participants' choices of colors were not homogenous between the three categories of products for American participants ($\chi^2(18) = 176.4, p < .05$) and French participants ($\chi^2(18) = 198.14, p < .05$). However, post hoc χ^2 test with Bonferroni correction ($\alpha = .0045$) showed that this non-homogeneity was only due to the food distribution in American panel, as post hoc χ^2 did not revealed significant difference in the distribution of choices for Personal Care product and Household product ($\chi^2(9) = 15.942, p = .068$). For the American panel, brown, orange, and pink-red were more often associated with food, while blue and white were more often associated with natural personal care products and household products (all $p < .0045$). In the French panel, brown was more chosen for food than for the other categories, and for personal care than for household product, green was more chosen for food than for non-food products, while orange and purple were more associated to natural food than to natural household product (all $p < .0045$). Blue was more chosen for household product than for the two other categories, and

more chosen for personal care than for food, while white was less chosen for food than for non-food products (all $p < .0045$).

3.2 Natural and artificial colors for strawberry

Regarding natural or artificial colors associated with strawberry, we conducted χ^2 tests between distribution of choices of colors and equal distribution to determine whether particular colors were perceived as natural or artificial for strawberry. For both natural and artificial associations with strawberry and both countries, χ^2 test revealed that choices of colors were non-random (natural colors for strawberry: France $\chi^2(17) = 785.63$, $p < .001$ and US $\chi^2(17) = 484.12$, $p < .001$, artificial colors for strawberry: France $\chi^2(17) = 104.23$, $p < .001$, and US $\chi^2(17) = 104.23$, $p < .001$). For both countries, post hoc χ^2 with Bonferroni correction ($\alpha = .003$) showed that dark red and bright red were chosen significantly more often than 5.5 % of the time for the question about natural colors for strawberry (France: bright red (34%), dark red (24%), US: bright red (29%), dark red (28%), all $p < .001$). For colors perceived as artificial for strawberry, only bright pink (8.2%) was chosen significantly more often than 5.5% of time in the French panel ($\chi^2(1) = 20.708$, $p < .001$). Surprisingly, bright pink (10%) and bright red (11%) were chosen significantly more often than 5.5% of time in the American panel (respectively $\chi^2(1) = 23.58$, $p < .001$ and $\chi^2(1) = 35.491$, $p < .001$), whereas bright red was also perceived as natural for strawberry.

3.3 Intensity

Participants expected medium intensity- between 4 and 5 on a scale from 1 to 8 - for both odors and colors and all categories of products: odors for natural food (4.27 ± 1.66), odors for personal care products (4.31 ± 1.73), odors for household products (4.36 ± 1.72), odors for strawberry (5.04 ± 1.63), colors for food (4.44 ± 1.66), colors for personal care products (3.93 ± 1.69), colors for household products (4.12 ± 1.79).

To examine how the categories of products or the demographic factors measured (country, age and gender) influence expectation of intensity, we performed two mixed (with between and within factors) analysis of variance (ANOVA). As meaning of “intensity” could differ between visual and olfactory modalities, we conducted one ANOVA for expected intensity of odors and another for expected intensity for colors. We then conducted post-hoc comparisons with Bonferroni-corrected t-tests ($p < .05$ prior to correction).

For odors, results revealed a significant main effect of Category of Product ($F_{3,1337}=113.6, p < .001$), due to significant higher expected intensity for the Strawberry odor (5.04 ± 1.63) than for Food (4.27 ± 1.66), Personal Care products (4.31 ± 1.73) or Household products (4.36 ± 1.72), but we found no significant differences between the three latter. We also found an effect of age ($F_{2,1339}=5.9, p = .003$), and post-hoc t-test showed that the younger the participant the higher the expected intensity was, as 18-34 years old (4.77 ± 1.76) expected higher intensity than 35-49 y/o (4.57 ± 1.68) and than 50 y/o and over (4.31 ± 1.69), and that 35-49 y/o expected higher intensity than 50 y/o and over. Results showed an effect of gender ($F_{1,1339}=45.5, p < .001$), reflected by the fact that men (4.80 ± 1.72) expected higher intensity than women (4.26 ± 1.68); and an effect of country ($F_{1,1339}=18.7, p < .001$) as American (4.76 ± 1.81) expected higher intensity than French (4.34 ± 1.63). Results also showed a significant interaction between age and category of product ($F_{6,2676}=5.1, p < .001$), and between gender and category of product ($F_{3,1336}=3.9, p = .009$). Mean scores are represented in figure 2.

The statistical analysis performed on expected intensity for colors showed a main effect of Category of product ($F_{2,1337}=68.8, p < .001$), as expected intensity was higher for food (4.35 ± 1.65) than for personal care products (3.93 ± 1.69) and for household products (4.12 ± 1.79), and it was higher for household products than for personal care products. Effect of age on expected intensity was also significant ($F_{3,1338}=2.9, p = .035$), with the 18-34 years old (4.59 ± 1.85) expecting higher intensity than 35-49 years old (4.16 ± 1.74), and than 50 years old and over (3.96 ± 1.62), and 35-49 years old expecting higher intensity than 50 years old and over. Results also showed an effect of gender ($F_{1,1338}=66.1, p < .001$), as men (4.58 ± 1.70) expected higher intensity than women (3.86 ± 1.68) and an effect of country ($F_{1,1338}=47.0, p < .001$), as American (4.58 ± 1.87) expected higher intensity than French participants (3.91 ± 1.58). Interactions between country and Product Category ($F_{2,1337}=10.2, p < .001$) and between gender and product Category ($F_{2,1337}=8.4, p < .001$) also reached significant level. Mean scores are represented in figure 3.

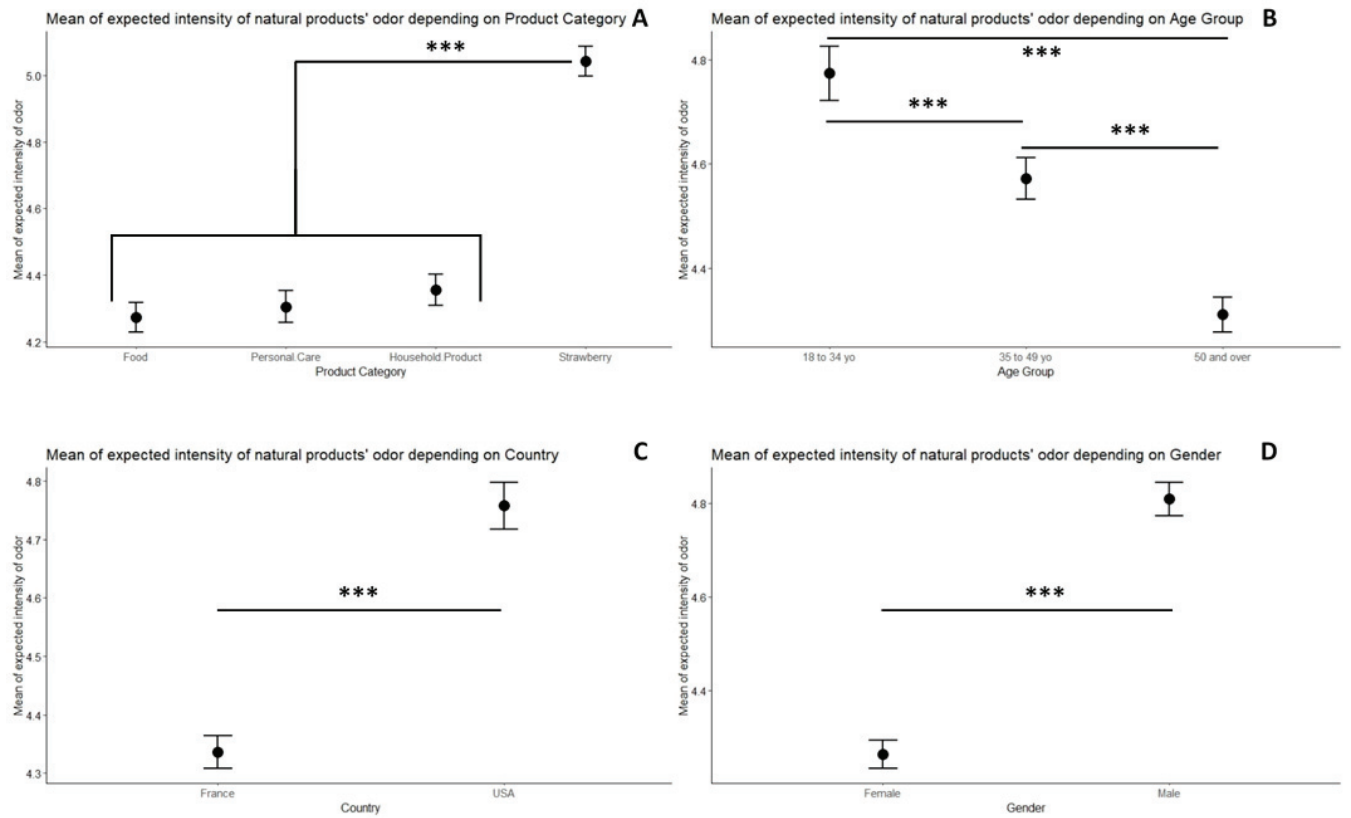


Figure 2: Mean of expected intensity of natural products' odor depending on the Product Category (A), the Age Group (B), the Country (C) or the Gender of the participant (D). Bonferroni corrected post-hoc test *** $p < .001$, ** $p < .01$, * $p < .05$, # $p > .05$

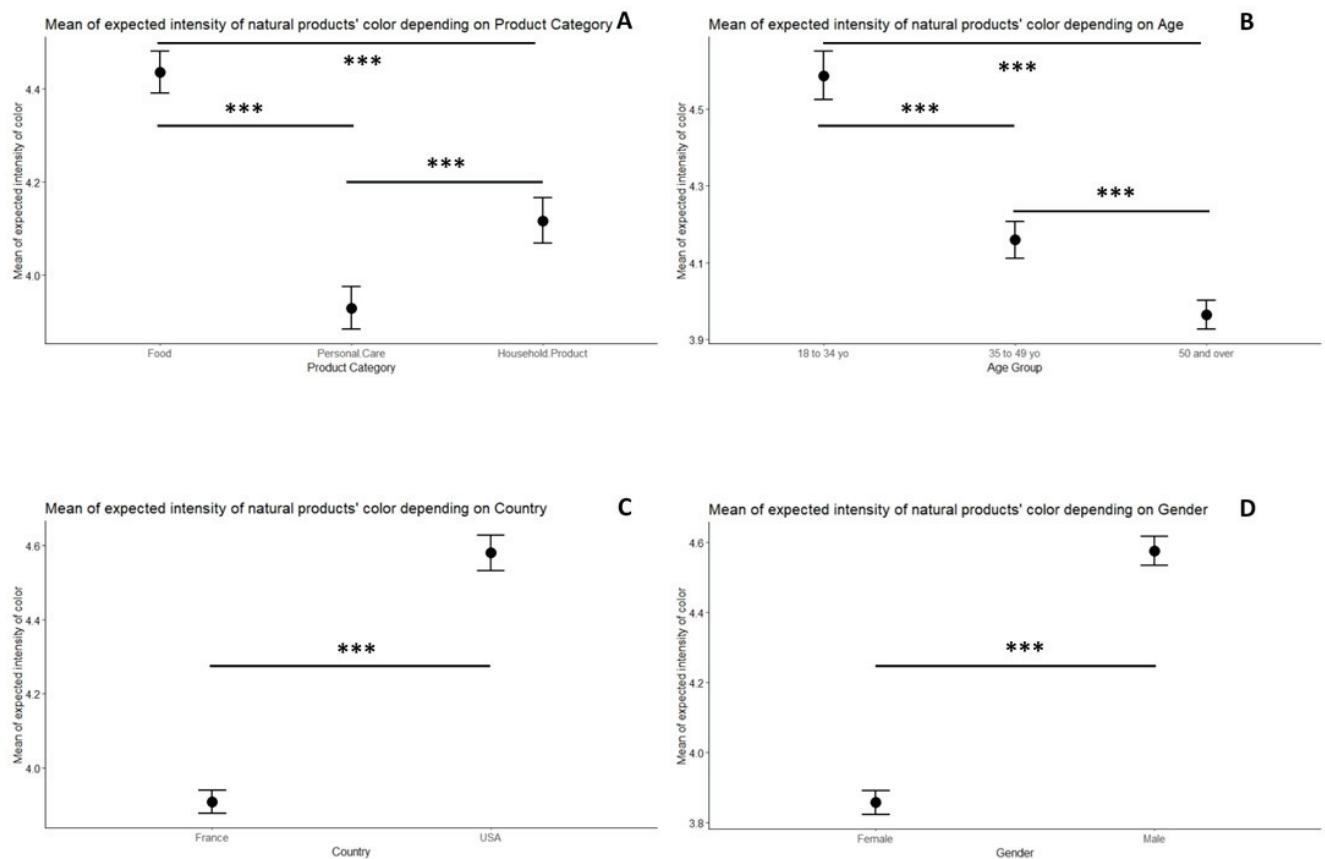


Figure 39: Mean of expected intensity of natural products' color depending on the Product Category (A), the Age Group (B), the Country (C), or the Gender (D). Bonferroni corrected post-hoc test *** $p < .001$, ** $p < .01$, * $p < .05$, # $p > .05$

3.4 Semantic association with odors

In a fourth analysis, we examined which words were the most associated with a natural odor, and which ones were associated with an unnatural odor. In France and in the US, “freshness” (7.9% for both countries) and references to flowers (respectively 6.3% and 2.8% of the corpus) were in the top three words associated with natural odors. For an unnatural odor, the word with most occurrences was chemical in both countries (18% of the corpus for the French sample, and 4.8% for the American sample).

Looking into the data, we also observed an emotional content associated with a natural or unnatural odor. For both countries, an unnatural odor was associated with adjectives of negative valence (15% of the corpus for the French sample, 28% for the American sample), like “bad”, “stinky” or “unpleasant”, but also with example of a somewhat unpleasant odor (3.3% for the

French corpus and 9.1% for the American corpus), like “hydrocarbons” or “rotten” object. On the other hand, a natural odor was associated with positive adjectives (10% of the French corpus and 8.1% of the American corpus), like “good” or “pleasant”, and with example of odors like flowers and plants.

We also observed associations with some specific sensory attributes. A natural odor was first associated with freshness (13% in French sample and 7.9% in the US sample). For the French sample, it was also associated with lightness and simplicity (respectively 6.8% and 4.1% of occurrences in the French corpus), and with cleanliness for American respondents (5.7% of occurrences). Unnatural odor was associated with strength (12% for French corpus, and 3.5% of occurrences for American one), pungency (3.9% for French corpus and 1.5% for American corpus) and with complexity for the French respondents (1.7% for French corpus, and 1% for American one).

This corpus of text brought us some elements of definition of natural or unnatural odors. An unnatural odor was first associated with “chemical”, in both countries. An unnatural odor was also associated with adjectives like “fake”, “artificial”, “human-made”, etc. while a natural odor was associated with “organic”, or “without additives”. Looking at the example of odors associated with naturalness, we observed that natural odors were associated with flowers, and more generally plants and natural kinds, while unnatural odors were associated with examples of manufactured object, like hydrocarbons, consumer goods, or fragrances. These elements suggest that a natural odor is both the odors of a natural object, like a flower, and an odor that was obtained naturally, like essential oil.

4. Discussion

4.1 Sensory attributes of naturalness

Previous studies highlighted effects of colors or tactile properties of packaging on perception of product’s naturalness (Ampuero & Vila, 2006; Labbe et al., 2013). However, few studies explored which sensory attributes are associated with naturalness. The first objective of our study was to investigate whether specific olfactory attributes and colors were associated with natural products.

For olfactory attributes, our findings revealed that freshness was the word most often associated with naturalness. This result is in accordance with the review of Roman and colleagues (2017),

who found that freshness was one of the expected attributes of natural products. However, freshness is a polysemic and ambiguous term, as it refers to a trigeminal sensation close to coldness, or also to a “level of closeness to the original product, in terms of distance, time and treatment” (Péneau et al., 2006, p.6; see also Fenko et al., 2009 for a discussion on freshness definition). Freshness, in the review of Romàn and colleagues, refers to this second meaning, and freshness in our corpus could refer to the freshness of an odorous object. However, associations with words like “smooth” for a natural odor or “pungent” for an unnatural odor also raise the issue of the trigeminal properties of natural odors. Additional results are needed to better understand which meaning of freshness participants referred to.

In a smaller but reliable extend, lightness was related to naturalness, as a natural odor was associated to adjectives like “light”, “subtle” while an unnatural odor was associated with adjectives like “overpowering” and “strong”. On the other hand, results from questions on expected intensity point out that participants expected medium intensity for odors of natural products. These elements suggest that consumers would expect artificial products to be more flavored or scented and thus to have stronger odor than natural products, rather than the fact that natural products have a weak odor.

The issue of complexity is also of interest, as natural odor was associated with “simple” and unnatural odor with “complex”. Most odors are complex mixture of molecules, but they are perceived and recognized as unitary discrete objects (Stevenson & Wilson, 2007). However, the ability of participants to discriminate odors mixed with three odors or more (e.g. mixture of strawberry, chocolate and rose) is low, even for familiar odors. Results also suggested that humans could only discriminate four components in odors mixture (Livermore & Laing, 1998). Thus, the meaning of complexity diverges between the chemical and perceptual level, as very complex mixtures could lead to very simple percept. Odors coming from natural objects are usually more complex at the chemical level than artificial ones. For example, a strawberry emits hundreds of aromatic molecules, while a strawberry flavoring does not exceed a few dozen different molecules. The association between naturalness and complexity would then occur at the perceptual level, a natural odor being a complex mixture of molecules leading to a simple percept, while an artificial one could be a more simple mixture of molecules but difficult to recognize as one object.

Moreover, in line with Apaolaza and colleagues (2014), our semantic corpus showed a distinction in terms of emotional valence, as words with positive valence were associated with natural odor, while words with negative valence were associated with unnatural odor. These results are in line with previous studies who underlined the positive attitude of the majority of consumers toward naturalness, and the prevalence of positive words in the free association with naturalness (Rozin et al., 2012). Moreover, if claims on naturalness are likely to trigger a halo effect on pleasantness and purchase intention (Apaolaza et al., 2014), blind tasting showed that natural food are not always those preferred by consumers (Hemmerling et al., 2016). Thus, tests with real odors would bring valuable results on the link between perception of odors' naturalness and hedonic judgment of odors.

For results from the part on associations between colors and natural products, three colors were reliably paired with natural products whatever the category of products or the country: green, white and yellow. As green is very often semantically associated with the natural kind (green vegetables, green space, etc...) this result is not surprising. Results of free associations with "natural" from Rozin and colleagues (2012), highlighted that plants and vegetables were more often cited than animals. Green, the color associated with plants, as noticed by the authors, was the color occurring most often in their corpus. The prevalence of green in participants' choices could be related to the fact that participants thought of natural products as plant-based products. Moreover, a previous study showed that a white background was perceived as more natural than an orange one for a fruit juice bottle (Ampuero & Vila, 2006). A possible explanation of this link could be found in the symbolic value of purity of white, as it is also an attribute associated with naturalness (Rozin et al., 2004). The association with yellow is more surprising, as no clear statistical or symbolic association links yellow with natural kinds.

However, results from the question about natural or artificial associations of colors with strawberry, outline the issue of typicality as mediating associations between colors and natural products. Indeed, red was considered as natural for the strawberry rather than green, white or yellow. A color would then be natural when it corresponds to the typical color of the natural object to which it is associated. This result is in line with findings on the effect of colors on smell perception. Indeed, the effect of colors on odor pleasantness ratings and identification was modulated by appropriateness of the association, i.e. if colors and odors were connected to the same source (like red for a strawberry odor)(DuBOSE et al., 1980; Zellner, 2013; Zellner et al., 1991). Thus, it is interesting to notice that three colors are associated to natural products

at the superordinate level (e.g. food, personal care products, or household products), but that by increasing the specificity of the category considered, the typicality becomes a more salient dimension. It is also of interest to notice that colors of the packaging convey information, and colors of the product itself convey other ones. Indeed, results from Zellner and colleagues (2018) suggest that color of the stimulus (e.g. a candy) is more important than the color of its packaging (e.g. its wrapper) for the consistency of the association with stimulus flavor. Thus, if green, yellow and white seem interesting to convey information about product's naturalness on the packaging, typicality would head manufacturers' choices on product's color.

4.2 Cultural disparities and disparities between product categories

The questions about intensity and choices of colors also highlights the issue of cultural disparities and of disparities between product categories in the perception of natural products' sensory attributes. Indeed, results showed that the American respondents expected higher intensity than the French respondents did. It could be explained by general higher intensity of odors and colors of products on American markets than on French markets, or also by a general cultural difference in the use of scales as cultural different pattern of response might occur (Lee et al., 2002). Cultural differences were also observed in the associations between colors and natural products, as green was more often chosen by Americans and white by the French participants. Once again, an unsolved question is: is this result explained by different co-occurrences of pairs of colors and natural products between the American and French markets, or else by cultural differences in the symbolic values assigned to these colors? Slight disparities were also observed in the semantic association with a natural odor. The most noticeable is that Americans, although they mainly associated positive adjectives with natural odors, also associated some negative adjectives with it (4.4% of the corpus), while French respondents associated almost no negative adjectives with natural odors (0.5% of the corpus). More than a question of attitude toward natural products, these results raise the issue of the cultural disparities in the attitude toward nature and wilderness. Indeed, verbatim words like "dangerous", "dirty", "stinky", "musty" in the text corpus from the American panel evoke an attitude of fear and disgust toward wilderness, which are one of the attitudes of humans toward nature (Kellert, 1995).

Results from question on associations between colors and natural products also provide evidence that perception of naturalness depends on the product category. Indeed, blue and white were more associated to non-food products than to food, while orange for example was more

associated to food. Moreover, as noted above, typicality also can trigger associations between colors and products. Thus, the underlying factors explaining these disparities are still unclear. They can rely on differences of statistical occurrences of colors for some product categories (e.g. few food are blue), differences in the perception of sensorial characteristics of products and thus matched colors (e.g. blue for freshness), or different symbolic representations of colors depending on the product categories (e.g. white for cleanness in household products) (see Spence, 2020 for a review on cross-modal associations between odors and colors). Results from questions on expected intensity provide less evidence for this point. For colors, expected intensity differed between product categories. These observed differences could arise from statistical reasons (i.e. statistically in consumer goods market, foods have more intense colors than the others products categories), or from structural reasons (e.g. as food are more arousing than non-food products, consumers expect more intense colors because they are also more arousing). Additional results are needed to further explore the underlying mechanism behind these differences of expectations. For odors, only the strawberry odor was expected to be stronger than the ones of the three other product categories. “Strawberry”, as being an example of fruit, could have been perceived as more natural than the other products categories, which regrouped objects that underwent some transformations. However, in this case, looking at the corpus results, the intensity for “strawberry” could have been expected to be lower than for other product categories as natural odors were expected to be light. To our knowledge, no other study explored the differences between categories of product in terms of naturalness perception and representation. Thus, these findings have to be considered as preliminary results on this question, and further studies are needed to supplement it.

Moreover, effect of age and gender on expected intensity were also founded, as the younger group of participants and men expected higher intensity for natural products’ color and odors than the older group of participants or women. Studies on influence of age on olfactory sensitivity brought evidence of deterioration of the sense of smell with age, and a decrease in smell sensitivity (Venstrom & Amoore, 1968). Moreover, gender differences on smell sensitivity are less consensual, some results suggesting that women have a more sensitive sense of smell, while others failed to find gender differences (Öberg et al., 2002). Thus, it seems unlikely that these differences of expected intensity arise from sensorial sensitivity differences between gender or age group. On another perspective, women and older consumers are also usually those with the most positive attitude towards naturalness (Román et al., 2017). Study

of the relation between attitude toward naturalness and expectations in terms of sensory attributes could be a fruitful avenue to better understand these results.

Last, but not least, results from semantics associations with natural or unnatural odors brought some interesting elements on what a natural odor is. Indeed, words associated with a natural odor like “without additives”, “unprocessed”, or also “extracted from a flower” suggest that naturalness of an odor depends on the production process of an odor, and the less transformed, the more natural. Moreover, the mention of objects like “flower”, “rose”, “grass” for natural odors, and like “gas”, “plastic”, “air freshener” for artificial odors, let us to think that a natural odor is the odor of a naturally occurring object, like a flower. Thus, these results raise an ambiguity on the definition of a natural smell.

4.3 Limitations and suggestions for future research

Some limitations have to be mentioned, and findings and conclusions should be taken with caution. A first limitation is in the nature itself of this study, which is an online survey. Indeed, these results come from declarative data, and are based on reported expectations and representations of natural products’ odors and colors. Further studies with olfactory testing are needed to test the strength of these findings. Such experiences would provide complementary results about the link between naturalness and intensity as well, and comparison between odors’ and colors’ intensity for natural and unnatural products would also be informative.

Another limitation concerns the association between colors and natural products, especially when dealing with the natural and artificial associations with strawberry. Indeed, the choice of colors was restricted to 18 colors, and thus the space of typical colors for strawberry was restrained. This element could explain why the same color was perceived as natural and artificial for strawberry for American participants. Indeed, as the question was formulated specifically for strawberry, it is possible that green, yellow or white hues were rarely chosen not because they were natural or artificial, but because they were perceived as unrelated to strawberry. The same question with a wider palette of colors could then lead to finer grain results, as slight differences in terms of hue or lightness could differentiate artificial from natural colors for strawberry. A replication with another object (lemon, grass, etc.) would also provide further elements to understand the association between color typicality and natural products. Moreover, food, personal care products and household products are very general categories. If results provide new insights in the consumers’ perception of natural products,

caution is needed for the extrapolation of these results to more specific categories. In particular, saliency of typicality of colors of the product could vary depending on the specificity level of the category. Moreover, as American and French markets are different, the objects considered typical for these categories could also differ between countries. Thus, seeing the name of the categories, the participants may have imagined different objects depending on their country. Observed differences between countries could come from differences of object's characteristics that participants had in mind when they filled the questionnaire, rather than differences of representation of product categories at the general level.

5. Conclusion

Taken together, our results highlight that naturalness is linked with a range of sensory and semantic attributes. Specific olfactory attributes, like freshness or lightness, were found to be associated with natural odors, while green, white and yellow were the three colors associated with natural products. Moreover, slight disparities in these associations were observed depending on the country or product category considered. Indeed, American participants had a preference for green and French participants for white, and American participants expected higher intensity of natural products' colors and odors. On the other hand, blue and yellow (and white for American respondents) were more associated with natural non-foods products, while brown, green, and orange (and pink-red and purple for American respondents) were more associated with natural food. Results on question about strawberry also raise the issue of color typicality in mediating associations. Such results could be insightful to better understand consumers' expectations towards natural products, and open new avenues of research for further studies. Sensory testing would bring important complementary results to our findings. Last, but not least, this study brings preliminary elements to consider the definition of a "natural odor". Results revealed an ambiguity on this issue, as a natural odor was both, 1) an odor produced naturally (e.g. essential oil), and 2) an odor that smells like a naturally occurring object (e.g. an odor of rose). New results are needed to disentangle this ambiguity on the definition of a "natural odor".

6. Declaration of conflict of interest

The author(s) declared no potential conflicts of interests with respect to the authorship and/or publication of this article.

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Interim Summary

This study 2 provided new evidence to clarify the concept of odor naturalness. First, the results of the questions with free association of descriptors with natural or artificial odors reinforce the ambiguity between the importance of the naturalness of the physical source (how the odorant was produced) and the cognitive level (what the odor smells like) in assessing the naturalness of odors. The results also draw our attention to several sensory dimensions related to the perception of naturalness, such as freshness, intensity and complexity. However, we observed a certain variability according to the context (the product category) or the cultures (France vs. US). Nevertheless, these results were based on participants' expectations about natural products properties rather than on their olfactory perception. In a third study, we therefore sought to explore these elements further with the evaluation of olfactory stimuli.

Study 3- Perceptual and cognitive factors modulating the naturalness of smells

Perceptual and cognitive factors modulating the naturalness of smells

Dantec M^{1,2,3§}, Allain H¹, Yvert N¹, Bensafi M³, Lafraire J²,

¹ Marketing, Sensory & Consumer Research, V. Mane Fils, Le Bar sur Loup, France

² Institute Paul Bocuse Research Center, Ecully, France

³ Lyon Neuroscience Research Center, CNRS-INSERM-University of Lyon, France

IN PREPARATION

§ Corresponding author

Centre de Recherche de l'Institut Paul Bocuse

Château du Vivier

1A Chemin de Calabert

69130 Ecully - FRANCE

Email: morgane.dantec@institutpaulbocuse.com

Abstract

Nowadays, there is a growing interest in natural products, which are expected to be superior to their non-natural counterparts. Studies on perceived naturalness have mainly focused on the factors modulating the perception of naturalness of objects. Although several factors related to the sensory characteristics of products have been identified, the contribution of the olfactory modality to perceived naturalness has been little studied. The aim of the present research was to study the factors modulating the naturalness perception of odors. Different levels of olfactory perception were considered: physical source, perceptual and cognitive levels. To meet our objectives, in the first study, 29 participants evaluated 33 odors from natural and synthetic odorants according to 6 perceptual dimensions and identified them. In a follow-up study (Study 2), we investigated the predictive value of odor identification on the evaluation of naturalness. Our results suggest that the perception of naturalness is mainly related to the dimensions of pleasantness, edibility, and intensity, and to identification processes. Furthermore, no differences in naturalness ratings were observed between natural and synthetic odorants. Overall, these results provide insight into the concept of naturalness in the olfactory domain and open up new avenues for research on naturalness to olfactory stimuli.

Keywords: Naturalness, odors, identification, natural, synthetic

1. Introduction

There is nowadays a growing desire for naturalness (Schösler et al., 2013; Vogt, 2007). While distrust increased towards synthetic chemicals such as pesticides and food additives (Lockeretz, 2007), naturalness has become a criterion of quality, especially in the food domain, as natural food is expected to be healthier, fresher, tastier, and more environmental friendly than non-natural counterparts (Román et al., 2017). Moreover, this growing desire for naturalness extends beyond the food domain, and recent empirical evidence suggests that contact with nature is beneficial for human well-being (Bratman et al., 2012; Pirchio et al., 2021; Taylor et al., 2018).

However, naturalness is a polysemic construct that can embed a wide range of different meanings (Borghini, 2014; Sandin, 2017; Siipi, 2008), and the properties of natural objects vary depending on the definition endorsed (Siipi, 2013). Naturalness may indeed refer to innate ability, authenticity, and realness, or familiarity for example (Siipi, 2008). Among naturalness meanings, naturalness as an absence of human influence might be of particular interest. Following this meaning, objects have been divided into two categories: on one side artifacts are human-made objects, created to meet some human needs, and on the other side are the natural kinds, which evolve independently of any human purpose (Katz, 1993). Neuroscientific and neuropsychological studies supported the cognitive relevance of this distinction by providing evidence of distinct neural and cognitive processing of naturally occurring objects vs. human-made objects (Joseph, 2001; Warrington & McCarthy, 1987; Warrington & Shallice, 1984). However, other authors argued that the categorization of some entities such as food and domesticated species in one or the other category is ambiguous, and that naturalness would thus be better represented by a continuum (Gelman, 1988; Siipi, 2008). The degree of naturalness varies along this continuum, modulated by the perception of human influence: the more transformed by human influence, the less natural an object is (Scott & Rozin, 2020; Siipi, 2008).

Several studies investigated the factors modulating naturalness perception, such as the nature of ingredients and the process applied to the product (Evans et al., 2010; Rozin, 2005), the level of processing (Evans et al., 2010), the length of ingredient list (Cheung et al., 2016), or even the level of mechanization of the production process (Abouab & Gomez, 2015). However, these studies explored naturalness perception by testing the impact of semantic or visual information on naturalness perception, and very few studies explored the perception of smells' naturalness. Yet, anyone who has ever enjoyed the smell of rain on warm earth knows that smells have as

much ability to evoke nature as images. In a study conducted by Mantel and colleagues, participants were asked to describe their experience after smelling 20 different odors. Their results showed that, in some cases, participants spontaneously referred to the naturalness of odors (Mantel, 2021). However, what makes a smell natural or artificial is still an open question.

Different levels of analysis may be considered to evaluate the naturalness of smells. The first level is that smells are related to their physical sources. The physical source emits volatile molecules able to enter the nasal cavity and interact with olfactory receptors (Buck & Axel, 1991). The binding of these molecules to the receptors leads to a cascade of biochemical and biological reactions (DeMaria & Ngai, 2010), leading to neural activation and perception of a subjective sensation, a smell (Dubois & Rouby, 2002). In a sense, smells are thus cues to the presence of physical objects in our environment, and the chemical message sends by this physical object shapes smell perception. In addition, although underestimated, humans have an impressive capacity for olfactory discrimination, as the human nose would be able to discriminate an extremely large number of smells (Malnic et al., 1999). Therefore, a difference in the naturalness of the physical source of the smell might result in a differential perception of smells' naturalness.

However, Herz (2003) found that discrimination between natural and synthetic sources does not exceed the chance level, suggesting that naturalness of the source is not the only parameter that modulates the perception of the naturalness of odors. Certain perceptual dimensions, such as intensity, may also modulate naturalness perception. For example, previous research suggested a negative relationship between the perceived intensity of smells and the perception of smells' naturalness (Dantec et al., 2022). Moreover, investigations conducted on the factors modulating naturalness shed light on the effect of familiarity on naturalness perception, as familiar ingredients are perceived as more natural (Chambers et al., 2018; Murley & Chambers, 2019). In the food domain, the naturalness dimension has also been related to emotional arousal perception. Indeed, transformed food was perceived as more arousing than natural food, which was, in contrast, more familiar (Padulo et al., 2018).

Nevertheless, perception is not exclusively determined by information provided by the stimulus (bottom-up) but is also influenced by the activation of information in long-term memory (top-down) (Solso et al., 2007). Studies on olfactory perception highlighted cognitive modulation of smell perception by top-down processing (Araujo et al., 2005; Dalton, 1996). Among this

information, elements influencing the identification of smells, i.e. association of a semantic label referring to a physical object, are of particular interest. Indeed, smells do not have proper names and are commonly named following their source, as it is the smell **of** something, e.g. an odor of strawberry, (David, 2002). This reference to the source, i.e. what the odor smells like (e.g. it smells like strawberry for example), might lead to a transfer of some properties of the source to the smell (Dubois, 2006). Cognitive modulation by providing smells labels has been found on the perception of smell's pleasantness (Djordjevic et al., 2008; Herz, 2003; Herz & von Clef, 2001; Kaeppler, 2019; Manescu et al., 2014), smell's intensity and arousal perception (Djordjevic et al., 2008), and even on psychophysiological response to smells (Djordjevic et al., 2008). De Araujo and colleagues (2005) found for example that the presentation of the label "cheddar cheese" or "body odor" modulate the pleasantness ratings of participants, even if they were exposed to the same molecule (isovaleric acid).

Considering the effect of odor names on smell perception, we might expect that the identification of odors influences the perception of smells' naturalness. Moreover, two studies found an effect of information about the source's naturalness on the perception of smells. Apaolaza and colleagues (2014), found that giving participants information about the naturalness of the physical smells' sources ("Perfumes made of 100% natural ingredients") increased pleasantness ratings of the olfactory percept compared to a condition without any information (Apaolaza et al., 2014, p.82). Herz (2003) also found that pleasant smells were perceived as more pleasant when presented as natural than as artificial. Her results also showed an effect of naturalness on safety perception, with natural smells being perceived as safer, (regardless of their actual source).

This latter result illustrates the difference between the actual physical source, i.e. the object emitting the volatiles molecules, like a flavoring in a jar, and the identified source, i.e. the object that participants associate with the smell, a strawberry for example. Misidentification or providing labels for the smells leads to the association of a source to the smell, which in fact can differ from the actual physical source. This distinction may have its importance. Indeed, although humans have a great capacity to distinguish odors, our ability to identify them is quite low, even for familiar odors (Cain & Krause, 1979; Engen, 1987). Furthermore, with advances in the food and fragrance industries, the relationship between odor and its source has become more ambiguous. Indeed, strawberry-flavored yogurt or apple-scented shampoo is now

available in the supermarket. Although the physical source is not a strawberry, the imitation of the chemical composition of a strawberry conveys a strawberry-like message.

Therefore, considering the above elements, we may assume that the naturalness of the physical source, perceptual properties of the smell, as well as identification of smells may influence naturalness judgments of smells. However, research on the naturalness of odors is scarce, and the evidence for the effect of these different elements is ambiguous and sparse. Therefore, we aimed in this paper to bring new elements to understand the respective influence of naturalness of the physical source, the naturalness of the identified source, and perceptual properties of smells on the perception of naturalness.

H1: Considering differences between natural and synthetic physical sources, and the human ability for smell discrimination, we assume that participants should be able to distinguish between natural and synthetic sources. Natural flavorings are thus expected to be perceived by participants as more natural than artificial ones.

H2: However, regarding the effect of smell identification on smell perception and the poor human ability to identify smells, our second hypothesis is that the evaluation of smells' naturalness will vary as a function of smells' identification. Even for the same molecule, identification is expected to vary between participants, and thus evaluation of smells' naturalness as well.

H3: As smells perceived as natural have been shown to be also perceived as more pleasant (Apaolaza et al., 2014; Herz, 2003), pleasantness is expected to be positively related to naturalness judgments.

H4: Given the overlapping between familiarity and naturalness meaning (Siipi, 2008), and that previous results found an effect of familiarity on naturalness perception (Chambers et al., 2018; Murley & Chambers, 2019), we also assume that familiarity and naturalness will be positively related.

H5: Contrariwise to familiarity, arousal was found to be, in the food domain, negatively related to naturalness perception (Padulo et al., 2018). We thus expected to find the same relation between arousal and naturalness in olfactory perception.

In order to test these hypotheses, the choice of odorants was restricted to a category of smell: strawberry. Strawberries are very common in France, and thus most of the participants were

expected to recognize the smell as familiar. Secondly, this fruit is a good example of the independence between the physical source (e.g. flavored yogurt, shampoo, or toothpaste), and the identified source (e.g. a strawberry), as there is a wide range of familiar strawberry-flavored products. As the range of flavored products is wide, the possibility of objects associated with this smell is also wide, as well as their naturalness. In addition, different types of odorants were included in our study: fragrances (i.e. odorants used in inedible consumer goods) and flavorings, with natural and non-natural flavorings following regulatory definition (Regulation (EC) No 1334/2008 of the European Parliament, 2008).

2. Study 1

2.1. Method

2.1.1. Participants

Twenty-nine French participants (24 females and 5 males), with age ranging from 20 to 48 ($M=37\pm 11.9$), were recruited. Participants were non-experts of smells (neither perfumers nor flavorists), and all participants reported normal olfactory function. Participation was voluntary and unpaid. This experiment, as well as study 2, was conducted in accordance with the declaration of Helsinki. Collection and storage of data respected rules and regulations for anonymization of data and safety of data storage.

2.1.2. Apparatus and stimuli

Participants smelled 33 strawberry odorants with different types of odorants: 11 were strawberry fragrances, 21 were strawberry flavorings used in different kinds of foods (dairy, confectionary, etc.), and 1 of these odors was a strawberry extract. Among flavorings, 11 were French flavorings and 10 were American flavorings to investigate cultural differences in the perception of naturalness. Among French flavorings, 5 were natural flavorings following French regulation on flavorings labels, i.e. molecules have been extracted from natural sources rather than obtained through chemical synthesis, and 6 were non-natural flavorings (Regulation (EC) n°1334/2008 of the European Parliament).

Odorants were diluted in mineral oil. The dilutions varied between odorants and were chosen to limit intensity variation between smells. 5ml of odorous solutions was put in an opaque flask of 15 ml (opening diameter 1.7 cm, height 5.8 cm), and a piece of polypropylene was rolled inside the bottle to prevent spilling and maximize odorant evaporation.

2.1.3. Procedure

To avoid olfactory fatigue, olfactory evaluation was split into 5 sessions, with 7 odors evaluated per session (only 6 odors for 2 sessions). Participants took part in all 5 sessions, except 5 participants who did not attend one of the sessions. At the beginning of a session, participants were seated in an individual cubicle, in front of a table on which were placed a computer and 6 or 7 jars (depending on the session) containing smells.

The session was divided into two tasks. In the first task, participants were asked to smell a specific jar, and then to evaluate the smell on Visual Analog Scales (VAS) following 6 dimensions: pleasantness, intensity, familiarity, arousal, naturalness, and edibility. The VAS ranged from 1 to 9 and was labeled at the anchors. A short definition of each dimension was provided above each scale to reduce ambiguity and misunderstanding.

After evaluating the smell, participants were asked to identify it. Identification tasks are sometimes limited to the aromatic note, e.g., strawberry, apple, or lemon (Engen, 1987; Thomas-Danguin et al., 2003). However, given the diversity of flavored products, the aromatic note is not sufficient to know if participants are referring to the fruit strawberry or strawberry yogurt. However, this distinction could explain a variation in the evaluation of the naturalness of the odors as the naturalness of the identified source differs. To capture the variation in the naturalness of the associated source, we decided to offer participants two levels of identification: 1) the odor category, or aromatic note (e.g., strawberry, apple, lemon), and 2) the product category (e.g. candy or chewing-gum, yogurt, shampoo, fresh fruit). First, participants identified the aromatic note of the smell by selecting the word that best matched in a list of 20 words. Then, they chose the category of product that best matched the smell, by selecting a name of a product category in a list of 16 words. After completing both tasks, participants were asked to smell a new jar. Within a session, participants smelled the same odorants, but the order of odorants' presentation was randomized between participants.

2.1.4. Design and data analysis

Data were analyzed with linear mixed models. After testing for participants and stimuli effects, these variables were set as random factors. Then, variables were added to the model one by one, and the model improvement in the fit of the data after the addition of a variable was tested (anova function). Analyses were conducted with R software, version 3.6.3. We set the alpha level at .05 for all statistical analyses.

2.2. Results

2.2.1. Effect of physical source and identification on evaluation of naturalness of smells

Following our first objective, we first investigated the effects of odorant types and identification. Thus, we built a first basic model and added our variables step by step. The addition of participants and stimulus as random factors improved the fit of the data (Table 1 in supplementary material) suggesting inter-individual variability in the perception of smells' naturalness and variability between odorants. Then, we added the two levels of identification (identification of the product category and the aromatic note), and the type of odorants (flavorings, fragrances, or extract) incrementally. Models' comparisons showed that the addition of the identification of product categories and aromatic notes increased the fit of the data, while the addition of the type of odorants did not (Table 1 in supplementary material). Analysis of the final model with the three variables yielded significant effects of identification of the product categories ($\chi^2(16)=120.3$, $p<.001$), and of identification of the aromatic notes ($\chi^2(20)=42.1$, $p=.003$), but no significant effect of the odorant types ($\chi^2(2)=2.5$, $p=.28$). The model satisfied the assumptions of normality, homogeneity of variance and non-collinearity of predictors.

Post-hoc Bonferroni corrected paired t-test showed significant differences in smells' naturalness depending on the categories of products identified (figure 1A). Surprisingly, post-hoc tests did not reveal a significant difference in smells' naturalness depending on the aromatic note identified, although this variable was significant according to the model (figure 1, B). Due to the high number of post-hoc paired comparisons, this lack of significant difference might be due to the Bonferroni correction which is conservative.

We then investigated the effect of the naturalness of the physical source on the sub-sample of French flavoring (11 flavorings, 5 natural and 6 non-natural). As previously, we added the two variables of identification and then the naturalness of the flavorings (based on the regulation of flavorings labels). As for analysis with all odorants, model comparisons showed that the addition of identification of product categories and aromatic notes increased the fit of the data, while the addition of the naturalness status of flavorings did not (Table 2 in supplementary material). Analysis of the final model with the three variables yielded significant effects of identification of the product categories ($\chi^2(16)=49.3$, $p<.001$), and of identification of the aromatic notes ($\chi^2(17)=34.7$, $p=.007$), but no significant effect of the flavorings' regulatory

status ($\chi^2(1)=1.53$, $p=.22$). The model satisfied the assumptions of normality, homogeneity of variance, but we observed a high correlation between the two levels of identification.

2.2.2. Effect of the dimensions of smell ratings on naturalness perception

To test our hypotheses 3, 4, and 5, we ran a linear mixed model with naturalness ratings as output. Participants and odorants were added as random factors. Then, standardized variables from the evaluation of smells were added one by one to the model. Model comparisons showed that the addition of pleasantness, edibility, and intensity increased the fit of the data (Table 3). Analysis of the final model yielded a significant effect of pleasantness ($b=.34$, $t(837)=9.14$, $p<.001$), the more pleasant the smell the more natural it was perceived. Results also showed a significant effect of edibility ($b=.20$, $t(726)=5.97$, $p<.001$, with the most edible smells perceived also as the most natural. A significant effect of intensity was also found ($b=-0.15$, $t(804)=-3.70$, $p<.001$, the more intense the smells the less natural it was evaluated; as well as a significant effect of arousal ($b=-0.11$, $t(869)=-2.24$, $p=.025$), with the more arousing smell being the less natural. Only the effect of familiarity did not reach significance ($b=.06$, $t(886)=1.34$, $p=.18$). The model satisfied the assumptions of normality, homogeneity of variance, and non-collinearity of predictors.

2.2.3. Inter-individual variability and consensus between participants

Interestingly, we observed in the previous models that the addition of participants and stimuli as random factors improved the model fit of the data, which illustrates the variability in the perception of naturalness between participants (figure 2A) and between stimuli (figure 2B). Moreover, a closer look at the perception of naturalness between stimuli reveals a strong inter-individual variability in the perception of naturalness even within smells. Indeed, as is represented in figure 2B, the range of naturalness ratings was broad, varying from one extreme to another for almost all the stimuli. In addition, the intraclass correlation coefficient (ICC) is very low for the stimuli ($ICC=0.024$) suggesting that the fraction of variability in naturalness ratings between stimuli is low compared to the total variability. This result suggests a poor consensus between participants about the perception of smells' naturalness.

Moreover, analysis of the identification of smells also suggests poor consensus in the identification of smells. Indeed, for each smell, identification varied between participants. On average 10 different categories of product ($M=10\pm 1.9$) and 8 aromatic notes ($M=8\pm 2.0$) were associated with the same smell. For the product categories, the greatest consensus achieved was

57%, with 16 participants associating the same category (candy) with one of the odorants. For the aromatic note, strawberry was the most frequently selected descriptor by participants for all odors (except one). Depending on the odor, strawberry was recognized by 18% to 92% of participants ($M=.54\pm.16$).

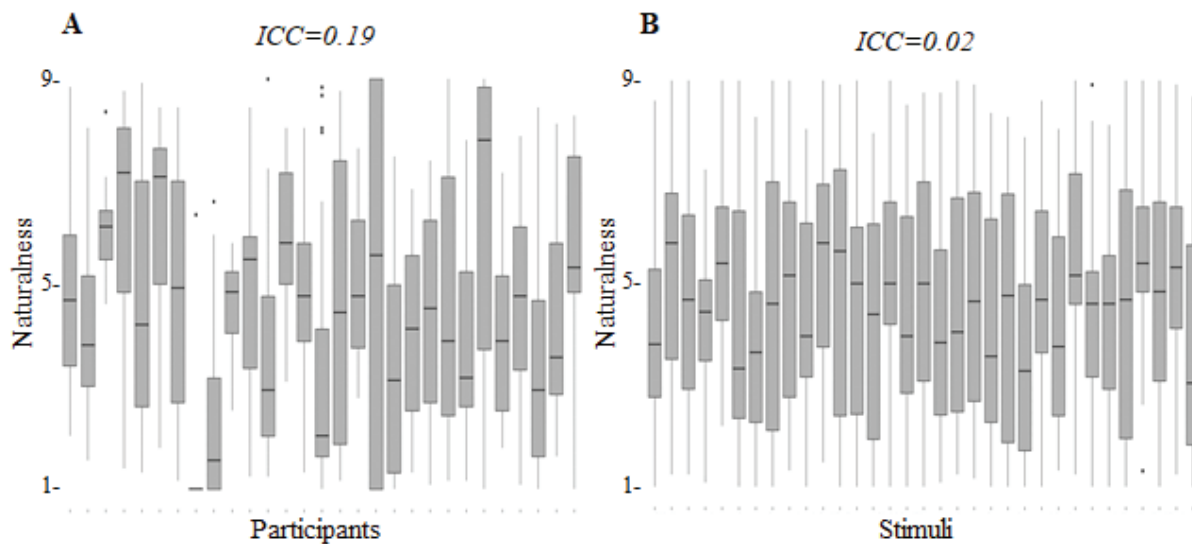


Figure 2: Distribution of naturalness ratings for each participant (A) and each stimulus (B)

2.3. Discussion

2.3.1. No difference between odorants

Contrariwise to our first hypothesis, we found no difference in naturalness evaluation between the different odorants. Indeed, fragrances were not perceived as more or less natural than flavorings. Similarly, our results did not show a significant difference in the evaluation of naturalness between natural flavorings and non-natural flavorings. Although the process followed to produce them differs between these two categories of flavorings, participants did not perceive differences of naturalness. The differences between natural and non-natural flavorings, and especially how the odorants molecules were produced, might thus be too small to be perceived by the human nose and to allow discrimination between natural and non-natural flavorings. This result is in line with the one of Rachel Herz (2003), who found that the distinction between natural and synthetic odorants was at chance level. Therefore, the naturalness of the physical source of the smell, in blind condition when participants do not have information about the physical source, may not influence the perception of smells' naturalness.

Nevertheless, a comparison between synthetic flavorings and real strawberries may yield a difference in the perception of naturalness as the chemical compositions of strawberry and non-natural flavorings are more different than between natural and non-natural flavorings. Indeed, two different dimensions differ between natural strawberry and non-natural flavorings. The first one is the naturalness status of the molecules, which are natural in one case and synthetic in the other. The other is the complexity of the chemical composition of odorant molecules, as the composition of strawberries is generally more complex than those of flavorings. As participants did not perceive differences of naturalness between natural flavorings and synthetic flavorings, the naturalness status of the molecules may not impact naturalness perception of the smells. However, important differences in the chemical complexity of odorants may lead to a different perception of naturalness. Further investigations are thus needed to disentangle the respective effects of naturalness regulatory status and the complexity of the chemical composition on the perception of the naturalness of smells.

2.3.2. Effect of dimensions of evaluation of smells

Moreover, our results also revealed relations between naturalness and other sensory dimensions, such as intensity. Indeed, the effect of intensity on naturalness perception was significant, and the most intense smells were also the less natural. This result is somewhat surprising, as the intensity variability was reduced based on a previous pre-test. Thus, even with low variability of intensity perception, the effect of intensity on naturalness ratings reached significance. Further experiments with a wider range of odor intensity could shed light on the link between intensity and perceived naturalness.

In addition, and in accordance with our third hypothesis, we found a significant effect of pleasantness on naturalness perception. This result is congruent with the studies reporting that most participants have a positive attitude toward naturalness and natural food (Romàn et al, 2017). Moreover, only few studies explored the relationship between perceived pleasantness and naturalness of smells. In accordance with the results of Apaolaza and colleagues (2014) and Rachel Herz (2003), we found a positive effect of pleasantness on naturalness perception. Nevertheless, our design does not allow us to draw any conclusion on the causality of this link. However, some elements suggest an effect of naturalness on pleasantness rather than the reverse effect. Indeed, Apaolaza and colleagues (2014) found a halo effect of naturalness on the pleasantness of smells: the modulation of naturalness perception also modulates pleasantness ratings. In addition, Herz (2003) observed that information about smells' naturalness increased

pleasantness ratings and that evaluations of pleasantness were affected by participants' categorization of smells as natural or synthetic. Considering these elements, one could hypothesize that naturalness modulates the perception of pleasantness rather than the contrary.

Our results also revealed a significant negative effect of arousal on naturalness evaluation. This relationship has been little explored in the literature, and there is little evidence to understand this connection. Padulo and colleagues (2018) found that natural food was perceived as less arousing than transformed food. Our results suggest that this negative relation between naturalness and arousal might be more general than the food domain.

Last, about the familiarity dimension, no effect significant effect of familiarity on naturalness perception was observed. As naturalness meaning may overlap with the familiarity dimension (Siipi, 2008), we would have expected that the most familiar smells would also be the most natural. This result cast doubt on the relevance of this particular meaning in the olfactory domain. The meanings associated with the naturalness of odors would deserve further examination, but it is reasonable to assume that they could be associated with the absence of human influence, as this is the most common meaning of naturalness (Siipi, 2008).

2.3.3. Effect of identification

Our second hypothesis was that identification should vary between participants, and thus smells' naturalness evaluation as well. Our results partly confirm this hypothesis. First, although the evaluation of naturalness varied between smells, suggesting an effect of the odorant on the perception of naturalness, the level of agreement between participants about each smell's naturalness was very low. At the same time, the identification of smells also varied between participants and the effect of the two levels of identification (aromatic note and category of product) on the evaluation of naturalness was significant. This latter result means that the identification of smell partially explains the variability in the evaluation of smells' naturalness. Therefore, our results suggest that more than the odorant, it is the identification of the smell that contributes to naturalness judgment.

Furthermore, smells associated with the most natural categories of the product, such as fruits, flowers, and juice, were on average evaluated as more natural than those associated with categories of products more artificial, such as household products or candy (figure 1). The naturalness of the object associated with the smell through identification may thus contribute to the evaluation of smells' naturalness by top-down processes. Following this interpretation,

we may predict that inter-individual variability in the perception of naturalness of the categories of products should result in variability in the evaluation of smells' naturalness even for a given category of products. For example, participants perceiving yogurt as natural should perceive the smells associated with yogurts as more natural than participants evaluating yogurt as artificial. For each participant, their evaluation of the naturalness of the category of products should predict the naturalness of the odorants based on their identification. To further understand the effect of identification of perception of smells' naturalness, therefore, we decided to conduct a second study aiming at testing the relationship between the naturalness of categories of products and the naturalness of smells based on their identification.

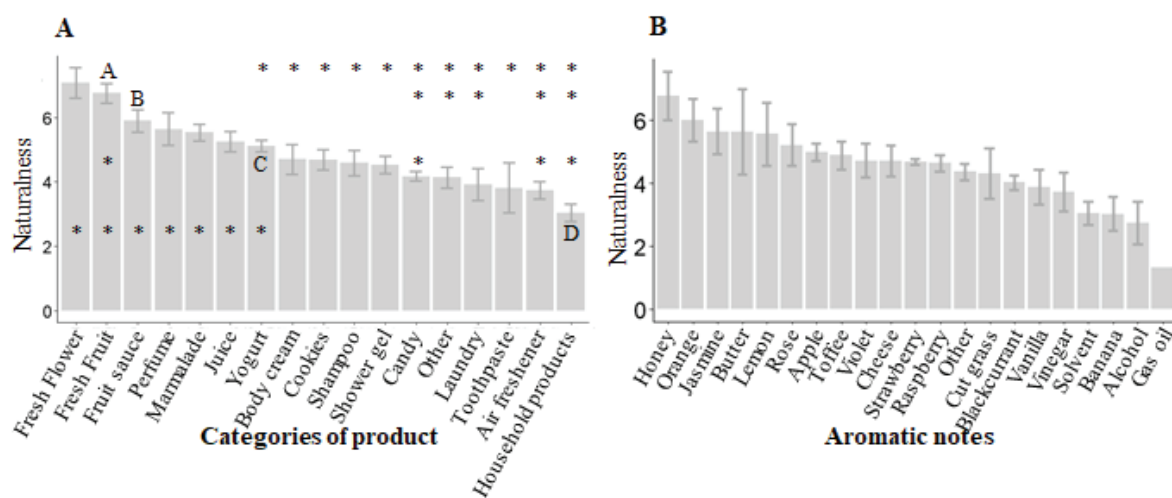


Figure 1: Mean of naturalness of smells depending on their identification in a category of products (A) or following the aromatic notes (B). Post-hoc tests are represented for the categories of products (A). The symbol * means that the average naturalness of smells in a given category is significantly different than the average naturalness of smells of the category with a letter on the same line, e.g. smells associated with candy were on average perceived as less natural than smells associated to the category fresh fruit.

3. Study 2

In this second study, we aimed to further understand the effect of cognitive factors on the perception of smell naturalness. In our first study, we observed that identification modulated the perception of the naturalness of smells. Furthermore, it seemed that the more natural the category associated with the smell, the more natural the smell was perceived. However, the

perception of naturalness of the categories of products might differ between participants. We then aimed to measure participants' perception of the categories of products, and determine for each participant to which extent their perception of the naturalness of the category of products is associated with the perception of naturalness of smells.

Moreover, beliefs and attitudes, i.e. evaluative disposition toward a psychological object, also modulate the perception of smells. Michel and colleagues (2019) found for example that participants with a very positive attitude toward naturalness perceived some objects as less natural than participants with a less positive attitude toward naturalness (Michel & Siegrist, 2019). Herz (2003) also assumed that natural smells were perceived as more pleasant because of participants' beliefs and attitudes toward naturalness. As we observed large inter-individual variability in the perception of the naturalness of smells, we investigated in this second study the relation between attitude towards naturalness and naturalness perception.

3.1. Method

3.1.1. Participants

Participants of study 1 were contacted again to participate in this second study. Sixteen of them, 13 females and 3 males, with age ages ranging from 58 to 28 ($M = 41 \pm 10.9$), agreed to take part in this second study.

3.1.2. Procedure

Participants answered a short questionnaire online via Qualtrics. The questionnaire was divided into two sections. In the first part, participants rated the naturalness of all the categories used for the identification tasks during the first study (20 categories for aromatic notes identification, and 16 categories for the category of product identification). Then, they completed the Product Naturalness Scale (PNS) (chapter 3), which aims at measuring the attitude toward naturalness for three categories of products: food, personal care products, and household products.

3.1.3. Design and Data Analysis

We investigated the effect of the naturalness of the aromatic notes and product categories on the perception of the naturalness of smells. First, we investigated the extent to which naturalness varied between the different categories. Then, for each stimulus and each participant, we associated the rating of the naturalness of the aromatic note and the category of product associated with the smell. For example, participant P1 identified the smell S1 as candy. Then,

we created a new variable, the category of product naturalness, and reported the evaluation of the naturalness of candy by participant P1 to the smell S1 (as it was identified as candy). We run a linear mixed model with naturalness of smells as the dependent variable, participants as the random factor, and evaluation of naturalness of product categories and aromatic notes as predictors.

The effect of attitude toward naturalness on the perception of smells' naturalness was investigated with linear models. The participants' average evaluation of naturalness was set as the dependent variable, and attitudes toward natural and artificial food, personal care products, and household products were added incrementally as predictors. Analyses were conducted with R software, version 3.6.3. We set the alpha level at .05 for all statistical analyses. The same analysis was conducted with pleasantness as the dependent variable.

3.2. Results

3.2.1. The naturalness of the aromatic notes and categories of products

We first controlled that naturalness evaluation varied between the aromatic notes and between the categories of products with linear mixed models. Online evaluation of the naturalness of these categories was set as the dependent variables and participants as random factors. Then, the identified aromatic note was set as the predictor in the first model, and identified categories of products variable was set as the predictor in the second model. Analysis of the first model revealed a significant effect of aromatic notes on naturalness ($\chi^2(19)=529.77$, $p<.001$), suggesting that evaluation of naturalness differed between the aromatic notes in the online study (study 2). Analysis of the second model revealed a significant effect of the category of products on naturalness ($\chi^2(15)=583.98$, $p<.001$), which means that evaluation of naturalness differed between the categories of product (a fresh fruit been for example evaluated as more natural than a laundry for example).

Then, the relation between the perception of smells' naturalness and the evaluation of the naturalness of the categories used for identification tasks was investigated. For each participant and smell, the evaluation of the naturalness of the aromatic note and product categories identified (study 2) were associated with the naturalness of the smell (study 1). First, we analyzed the correlation between the evaluation of naturalness of aromatic note categories (e.g. average evaluation of strawberry naturalness) and the average perceived naturalness of smells identified following these categories (e.g. average naturalness of smells identified as

strawberry). the correlation between the evaluation of naturalness of product categories (e.g. average evaluation of yogurt naturalness) and the average perceived naturalness of smells identified following these categories (e.g. average naturalness of smells associated with yogurt category) was significant ($r=.77$, $p<.001$, figure 3A). However, the correlation was not significant for aromatic notes ($r=.35$, $p=.15$, figure 3B).

Analysis of results with linear mixed model yields quite similar results. The naturalness of smells (study 1) was set as the dependent variable, participants, and stimuli as random factors, and the naturalness of categories of product and aromatic notes (study 2) were added incrementally as predictors. Comparisons of models reveal that the addition of the evaluation of the naturalness of the categories of products significantly improved the fit of the data (Table 4 in supplementary material), while the addition of the evaluation of aromatic notes' naturalness in the model did not. Analysis of the model with the two predictors shows a significant effect of the categories of products naturalness ($\chi^2(1)=41.11$, $p<.001$), while the effect of aromatic notes' naturalness was not significant ($\chi^2(1)=.85$, $p=.36$).

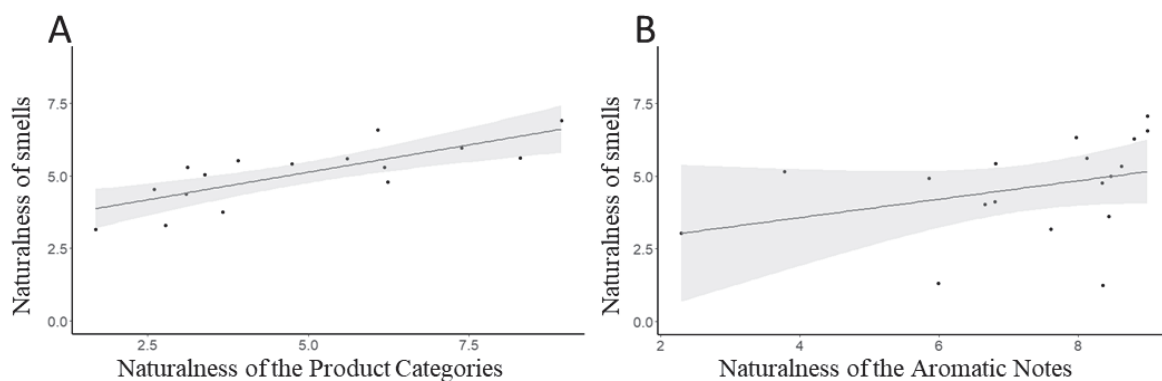


Figure 3: Correlations between the naturalness of smells and the naturalness of the categories of products (A) or with the naturalness of aromatic notes (B).

Each point represent the average evaluation of the naturalness of a category in online study (e.g. Yogurt for figure A or Strawberry for figure B), and the average naturalness of the smells associated with this category during identification task in evaluation of smells study (e.g. smells identified as Yogurt for Figure A or identified as Strawberry for figure B).

3.2.2. Attitude

The effects of the different measures of attitude toward natural products on the perception of smells' naturalness were not significant. Indeed, no addition of any variables significantly improved the fit of the data (all $ps > .01$), and no effect of the variables included in the final model (with all the variables) reached significance (all $ps > .01$). Analysis of the effect of attitude on the perception of smells' pleasantness yields similar results, as no addition of any variables significantly improved the fit of the data (all $ps > .01$), and no effect of the variables of the model with all the variables reached significance (all $ps > .01$).

3.3. Discussion

3.3.1. Effect of aromatic notes and product categories naturalness on smells naturalness

This second study provides interesting results that complement the results of the first study. Participants evaluated the naturalness of the categories used for the identification task of study 1. Analysis of naturalness evaluation showed that it varies between the aromatic notes categories and between the products categories. Moreover, the addition of categories of products' naturalness as predictors of smells' naturalness evaluation improved the fit of the data. The significant effect of categories of products' naturalness to explain smells' naturalness evaluation reinforces the results of study 1 suggesting cognitive modulation of smells' naturalness perception. Indeed, the most natural smells were also those associated with the most natural categories of products.

However, the addition of aromatic notes' naturalness as predictors of smells' naturalness evaluation did not improve the fit of the data. This result might seem surprising, as the effect of aromatic notes identification was significant in our first study. This finding may be explained by the low variability in the evaluation of aromatic notes' naturalness and our limited sample of participants. Indeed, even if naturalness varied among the aromatic notes, the effect was mainly driven by a few categories (mainly solvent, alcohol, and gas oil), while most of the categories were evaluated as very natural (honey, rose for example). This lack of variability might hide the effect of aromatic notes' naturalness to explain the evaluation of smells' naturalness. However, another explanation may underline this result. When evaluating aromatic notes' naturalness, participants probably evaluated the naturalness of the object associated with the aromatic notes' names, such as the naturalness of the fruits such as strawberry, apple, and lemon.

However, when they identified the smells as strawberry, apple, or lemon, they were not necessarily thinking of the fruits, but maybe of a product flavored with strawberry, apple, or lemon flavor. This mismatch between the object evaluated during the evaluation of the aromatic notes and the actual object associated with the smell could explain the lack of correlation between the naturalness of the aromatic notes and the naturalness of the smells.

3.3.2. Attitude

Results did not show any effect of the attitude toward naturalness on the perception of smells' naturalness or pleasantness. As Michel and colleagues (2019) found that attitude toward naturalness was related to the perception of naturalness, we expected to find a relation between these variables. Two different explanations are plausible for this result. The first one is that there is no relation between the attitude toward naturalness and the perception of smells' naturalness or pleasantness. The second explanation might be that there is a relation, but the effect was not significant due to the size of our sample.

4. General discussion

Results of the two studies support an effect of identification on the evaluation of smells' naturalness. In study 1, the effects of the two levels of identification on naturalness evaluation were significant. Moreover, in study 2, results revealed a significant effect of the naturalness of the category of product on the naturalness of smells. The naturalness of the object associated with the smell through identification process may thus influence the perceived naturalness of the smell. However, we cannot exclude that the perception of the naturalness of the smells shaped odor identification rather than the reverse. Indeed, although our result found a relationship between these variables, we did not test a direct effect of identification on naturalness perception. Moreover, the effect of labels on smell perception is still under debate. Evaluation of perceptual features, such as pleasantness, for example, may indeed occur early in smell perception, even ahead of odor naming. At the same time, evidence has been provided that smells' object representation occurs also quickly during smells processing (see Kaeppler et al., 2018 for a discussion on this point). Further investigations are thus needed to better characterize the relation between the perceived naturalness of smells and the identification process.

Furthermore, results on identification effect brought interesting methodological elements about the identification tasks. Indeed, the effect of aromatic notes was significant in our first study,

but not in the second study. This result may come from a mismatch between the object evaluated during study 2, e.g. a strawberry, and the object actually associated with the smell, e.g. a strawberry candy. Identification restrained to the aromatic note level might therefore only partially account for smells representation and identification. Indeed, for a given aromatic note, a great diversity of objects can be associated with the smell. This point should be considered when investigating the relationship between smells' identification and smell perception, or for cross-modal studies such as associations between smells and colors.

Interestingly, we also observed that although we used only strawberry smells, participants identified different aromatic notes. This is probably partially due to participants' poor ability to name smells, but it could also be due to variability in the quality of smells and their distance from real strawberry smells (Cain, 1979).

Results also revealed a positive effect of pleasantness, edibility on naturalness, and a negative effect of intensity and arousal on naturalness. The effect of pleasantness is in line with previous research on naturalness and pleasantness perception of smells (Herz, 2003; Apaolaza et al., 2014). Moreover, although effects of intensity and arousal on naturalness perception have been found with the evaluation of images (Padulo et al., 2018 ; Dantec et al., 2021), no study extend these results to olfactory stimuli evaluation. However, contrariwise to previous findings (Chambers et al., 2018; Murley & Chambers, 2019), we observed no effect of familiarity on naturalness evaluation. Moreover, our design limits us to the observation of relations, and further research is needed to test the causality effect of dimensions such as intensity on naturalness perception.

Last, we observed no difference in naturalness ratings between the different odorants, or between natural and non-natural flavorings. In addition, we observed great variability in the evaluation of naturalness within smells, suggesting a poor consensus about naturalness evaluation.

Taken together, these results highlighted that perceptual and cognitive factors influence the perception of naturalness of smells. Although the level of the physical source did not appear as modulating naturalness judgments in our studies, further elements are needed to conclude about the effect of naturalness status of odorants (natural vs synthetic) and chemical complexity (simple flavoring vs complex real odorants) on the perceived naturalness of smells. In addition, we tested the effect of this dimension in blind conditions (participants did not have information

about the odorants). However, considering Apaolaza and colleagues (2014) results, we assume that information about the odorants naturalness would probably influence naturalness perception.

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Supplementary material

Table 1: Model comparison of effects of identifications levels and odorant types

Sampling Units		N Subjects =29 ; N odorants = 33							
Model	Fixed effects added	Random Effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
basic	-	-	-	3957	3967	-1977	2		
Random 1	-	Intercepts	-	3847	3862	-1921	3		
Random 2	-	Intercepts	Intercepts	3843	3862	-1918	4	1	6.45*
1	Identification product category	Intercepts	Intercepts	2312	2407	-1136	20	16	1563***
2	Identification product category + Identification Aromatic Note	Intercepts	Intercepts	2311	2502	-1115	40	20	40.8**
3	Identification product category + Identification Aromatic Note + Odorants type	Intercepts	Intercepts	2312	2513	-1114	42	2	2.46

Table 2: Model comparison of effects of identification levels and flavoring types

Sampling Units		N Subjects =29 ; N odorants =33							
Model	Fixed effects added	Random effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
basic	-	-	-	1303	1310	-649	2		
Random 1	-	Intercepts	-	1265	1276	-629	3		
Random 2	-	Intercepts	Intercepts	1263	1278	-627	4	1	3.72 ·
1	Identification product category	Intercepts	Intercepts	788.7	862.4	-374	20	16	506***
2	Identification product category + Identification Aromatic Note	Intercepts	Intercepts	790.1	926.5	-358	37	17	32.6*
3	Identification product category + Identification Aromatic Note + Odorants type	Intercepts	Intercepts	790.7	930.8	-357	38	2	1.43

Table 3: Model comparison of effects the different perceptual dimensions on naturalness evaluation

Sampling Units		N Subjects =29 ; N odorants =33							
Model	Fixed effects added	Random effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
Random	-	Intercepts	Intercepts	3843	3862	-1918	4		
1	Pleasantness	Intercepts	Intercepts	2279	2303	-1134	5	1	15.66 ***
2	Pleasantness + edibility	Intercepts	Intercepts	2240	2303	-1134	6	1	41.0 ***
3	Pleasantness + edibility + intensity	Intercepts	Intercepts	2208	2241	-1097	7	1	33.8 ***
4	Pleasantness + edibility + intensity + arousal	Intercepts	Intercepts	2206	2245	-1095	8	1	3.58
5	Pleasantness + edibility + intensity + arousal + familiarity	Intercepts	Intercepts	2207	2250	-1094	9	1	1.75

Table 4: Model comparison of effects the naturalness of the identified source (study 2) on naturalness of the smell (study 1)

Sampling Units		N Subjects =16 ; N odorants =33							
Model	Fixed effects added	Random effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
Random	-	Intercepts	Intercepts	1291	1308	-642	4		
1	Natural of product categories	Intercepts	Intercepts	1252	1273	-621	5	1	41.3 ***
2	Natural of product categories + Natural of aromatic notes	Intercepts	Intercepts	1278	1278	-620	6	1	.85

Interim Summary Chapter 4

These studies highlighted the effect of different factors on the perception of the naturalness of odors. First, in relation to our fourth hypothesis, the studies highlighted the high inter-individual variability in the evaluation of the naturalness of odors. Furthermore, related to our first hypothesis, we did not observe differences in naturalness between natural and synthetic odors (Study 3), although Study 2 suggested that this level was involved in assessing naturalness. At the perceptual level and in support of the second hypothesis, results revealed positive relationships between pleasantness, edibility, and naturalness, and negative relationships between intensity, arousal, and naturalness. Furthermore, in support of our third hypothesis, the results especially highlighted the importance of the cognitive level, and particularly the effect of odor identification. As mentioned in the chapter 2, part 3, associating a semantic label to the odor through identification leads potentially to a transfer of properties from the identified source to the perception of the odor through top-down processes. We might therefore suspect that naturalness is a property of the object rather than a property of the stimulus. Consequently, naturalness could be an amodal property, transcending sensory modalities. Therefore, in a fourth study developed in the next chapter, we sought to test this hypothesis.

Chapter 5- Implicit measurement of naturalness of smells

The purpose of the study developed in this last experimental chapter was to test, using implicit methodologies, the hypothesis that naturalness crosses sensory modalities. Thus, we set up an experiment testing the association between odors and images representing natural entities or human-made objects. The use of implicit methodologies also allowed us to challenge the results previously obtained by declarative methods. Indeed, although still poorly understood, numerous publications have highlighted differences in constructs measured with explicit or implicit methods. Among these methods, the implicit association task (IAT) has been adapted to the olfactory domain. In the following article, we present the implementation of an IAT testing the association between images and odors representing natural entities or artificial objects, on two samples, one in France and one in the United States.

Study 4- Congruent associations between natural images and natural odors

Congruent associations between natural images and natural odors

M. Dantec^{1,2,3}, H. Allain¹, N. Yvert¹, M. Thevenet², M. Bensafi², J.Lafraire³

¹ V. Mane Fils, Marketing, Sensory & Consumer Research, Le Bar sur Loup, France

² Institut Paul Bocuse Research Center, Ecully, France

³ Lyon Neuroscience Research Center, Neurobiology and Plasticity of Olfactory Perception Team, University Lyon1, Inserm U1028 - CNRS UMR5292, Lyon, France

IN PREPARATION

[§] Corresponding author

Centre de Recherche de l'Institut Paul Bocuse

Château du Vivier

1A Chemin de Calabert

69130 Ecully - FRANCE

Email: morgane.dantec@institutpaulbocuse.com

Abstract

Naturalness is more than a marketing trend. Neuroscientific studies have provided evidence of distinct cognitive and brain processing of natural objects compared to human-made objects. However, these studies have focused on the visual modality and little is known about olfaction. While odors do not appear to be any less able to evoke nature, whether naturalness shares the same meaning between the visual and olfactory domains is not clear. Images have been considered natural when they represent natural objects. Thus, one assumption that can be made is that, as with images, the naturalness of a smell would depend on what that smell evokes (i.e., a natural or human-made entity). Following this hypothesis, we set up two implicit association tasks testing the association between odors and images representing natural or human-made objects in French (Study 1) and American (Study 2) samples. In these tasks, participants were asked to classify images and odors as quickly as possible into one of four categories: fruit (natural) or candy (artificial) for odors, mountains (natural) or buildings (artificial) for images. Participants were expected to be faster in the congruent condition, i.e., when fruit smells and mountain images shared the same response key, than in the incongruent condition, i.e., when fruit smells and building images shared the same response key. An effect of condition (congruent vs. incongruent) on reaction time was observed in the French sample only. However, in the US sample, the interaction between condition presentation order and condition was also significant. Further analysis revealed that the effect of condition was significant only in the group exposed to the congruent condition first. Overall, these results suggest that smells and images are associated based on the naturalness of the object they represent, suggesting that naturalness transcends sensory modalities. The elements also highlighted the importance of cognitive processes in the perception of naturalness.

Key words: Naturalness, olfaction, vision, implicit association task, crossmodal correspondences

1. Introduction

There is nowadays a growing demand for naturalness. In the food domain, naturalness is one of the main factors explaining food choice (Steptoe et al., 1995), and naturalness is perceived by a majority of consumers as an indicator of food quality, as natural foods are believed to be healthier, more environmentally friendly, fresher, and tastier than their non-natural counterparts (Román et al., 2017). Furthermore, Paul Rozin and colleagues (2004) have shown that the preference for natural products is not only based on an instrumental motivation, i.e. the belief that natural products are healthier, more environmentally friendly, or tastier but that it is also based on an ideational motivation, i.e. the “the desirability of natural per se (for moral or ideational/aesthetic reasons)” (Rozin et al., 2004, p.152). Wilson and Kellert (1993) went even further by hypothesizing an innate need for contact with nature, and that humans would have innate biophilia (Kellert & Wilson, 1995). Besides, recent results showed that contact with nature improves well-being (Bratman et al., 2012; Pirchio et al., 2021; Taylor et al., 2018).

Studies in neuropsychology and neuroscience have supported the psychological relevance of the naturalness dimension, by generating evidence about distinct cognitive and neural processing between natural kinds (the naturally occurring object), and the artifacts (the human-made objects). Indeed, cases of category-specific agnosia between natural kinds and human-made objects supported the assumption that these categories may be processed by different cognitive systems (Rumiati & Foroni, 2016). Moreover, results from neuroimaging studies showed a differential pattern of brain activation in response to the presentation of images of artifacts or natural kinds (Joseph, 2001). Cichy and colleagues (2014) even found that the discrimination between images of natural kinds and artifacts might occur early (around 122ms), reinforcing the hypothesis of the importance of naturalness (Cichy et al., 2014).

However, these studies on naturalness perception focused on the visual domain as most of the studies used visual stimuli, with images of natural kinds and artifacts. In these studies, the naturalness dimension relied on the perceived absence of human influence: artifacts are human-made objects created to fulfill a function, while natural kind occurs naturally without human intention (Katz, 1993). However, considering the differences between the visual and olfactory domains, it is not clear that naturalness may follow the same meaning in olfaction as in vision. Indeed, images have the advantage of being mostly unambiguous about the object they represent, as the objects represented by the stimuli are easily identified. Smells, on the other

hand, are much more difficult to identify, as even familiar smells are only poorly identified (Cain & Krause, 1979; Engen, 1987). Therefore, one may wonder if the naturalness of smell may rely on smells representation as for images.

Two major difficulties hinder the definition of a natural odor. The first one is the polysemy of naturalness. Indeed naturalness encompasses different meanings. An object can be considered natural because it has not been modified by human influence, or because it is perceived as familiar, common, or even real and authentic (Siipi, 2008). This polysemy has introduced variability in the definition of "natural" olfactory stimuli. Indeed, the definition of naturalness has fluctuated for odors, with the term "natural" referring to the use of fruits and vegetables (Johnson et al., 2010; Ruebenbauer et al., 2008), real objects even if they were not natural kinds, such as peanut butter or baby powder (Cain & Krause, 1979), body odors without fragrances (Gaby & Zayas, 2017), or essential oil as stimuli (Apaolaza et al., 2014; Lehrner et al., 2000).

Moreover, another difficulty to capture the significance of naturalness in olfaction lies in the fact that different levels involved in the perception of odors can be considered to evaluate the naturalness of odors: the physical source, perceptual or cognitive levels. The studies mentioned above considered the physical source' properties to set the naturalness of smell, by setting the naturalness of the physical stimuli as the defining feature of smell naturalness. However, previous studies conducted on the discrimination of natural and synthetic odorants suggested that, in absence of any information about the naturalness of the odorant, participants do not discriminate naturalness of natural vs synthetic odorants (Herz, 2003; Chapter 4 Study 3). Therefore, the naturalness of smells might not be only modulated by the properties of the physical source. In addition, although some results suggest that sensory characteristics of smells may be related to the perception of naturalness, such as intensity, most of the evidence suggests a cognitive modulation of the naturalness of smells (Apaolaza and al., 2014). Apaolaza and colleagues (2014) found for example that giving information about the naturalness of the smells modulates the evaluation of smells' naturalness. In addition, other results point out the importance of identification of smells: smells associated with a semantic label referring to a natural object are evaluated as natural, although the actual physical source is artificial (Herz , 2003).

The above results suggest that, as for images, a smell might be natural when evoking a natural object. Therefore, an assumption may be that naturalness is a dimension that cuts across the

sensory modalities. More specifically, naturalness in both visual and olfactory modality may rely on the stimulus representation: does the smell or image represent a natural kind or a human-made object. In the present study, we aimed to test these assumptions by investigating the crossmodal association between images and odors as a function of the naturalness of the objects they represent. Following this hypothesis, we set up an implicit association task (IAT) to test the association between odors and images representing natural or artificial objects.

The IAT has been designed by Greenwald and colleagues (1998) to investigate automatic associations between concepts, such as flower and insect, and attributes, such as good and bad. In this test, participants have to categorize target stimuli (e.g., pictures, words) into one of four categories (e.g. flower, insect, good and bad). There are two conditions of interest in the test, depending on the place of the categories on the screen. The associated categories (e.g., good and flower) are in the same corner of the screen and thus share the same response key in the congruent condition. The condition when the dissociated categories (e.g., good and insect) share the same response key is the incongruent condition. The interest of the IAT relies on the observation of the congruence effect and the facilitation effect: participants categorize target stimuli faster in the congruent condition than in the incongruent condition, suggesting a facilitation effect, i.e. that it is easier to categorize targets when the associated concept share the same response key (Greenwald et al., 1998). The IAT has several advantages, and in particular that it provides information that differs from traditional explicit scoring by avoiding direct questioning (Gawronski & Hahn, 2018).

Furthermore, IAT has been successfully adapted to the study of sensory perception, such as for the study of crossmodal correspondences between visual and auditory modalities (Parise & Spence, 2012; Peiffer-Smadja & Cohen, 2019; Roque et al., 2020). IAT has also been adapted to the olfactory domain, to study crossmodal correspondences between colors and smells (Luisa Dematte, 2006), images and smells (Lemercier-Talbot et al., 2019), conceptual attributes and smells (Lemercier-Talbot et al., 2019), or also olfactory-tactile associations (Luisa Demattè et al., 2007).

However, these IATs used olfactometers to deliver smells to the participants and measure reaction time (RT) of participants. The olfactometer, although it allows total automation of smells delivery, is limited to the use of monomolecular odorants. Indeed, the difference in molecular weight, and thus the speed of the molecules in the olfactometer, influence the timing

of their arrival in the participant's nose. Therefore, the use of the olfactometer may disturb the perception of odors for multimolecular mixtures (Nicolas & Bensafi, 2021). We thus choose to proceed with a different delivery method to measure reaction time. This method was adapted from Manesse and colleagues procedure (2020). In this method, smell delivery was manual, with the experimenter putting a flask 1 cm under the participant's nose. At the same time, a nasal cannula allowed to record sniffing behavior. This method enables the measurement of reaction time, by measuring the latency between the beginning of smell perception, i.e. when the participants breathe in after flask presentation, and participants' response.

The aim of our study was thus twofold. First, we aimed at investigating crossmodal associations between images and smells representing naturally occurring objects, and between images and smells representing human-made objects. Considering our assumption, participants were expected to be faster in the congruent condition (when natural images and smells share the same response key) compared to the incongruent condition (when natural images and artificial smells share the same response key). We also expected an effect of modality, as previous studies using IAT with images and smells found that images are categorized faster than smells (Lemercier-Talbot et al., 2019; Luisa Dematte, 2006). Second, we sought to develop a new method for setting IAT with visual and olfactory stimuli without using an olfactometer for odor delivery by adapting to IAT the procedure developed by Manesse and colleagues (2020) for priming tasks (Manesse et al., 2020).

2. Study 1

2.1 Method

2.1.1 Participants

34 French participants were recruited for this study, 21 females and 13 males, with 3 participants being between 18 and 24 years old, 17 being between 25 and 34 y/o, 7 being between 35 and 44 y/o, and 6 being between 45 and 54 y/o. All participants reported no olfactory, visual, or motor impairments.

2.1.2 Apparatus and stimuli

To test the association between images and smells representing natural objects and between images and smells representing human-made objects, 4 categories were chosen: 2 categories of natural objects and 2 categories of human-made objects (Table 1). Great attention was paid to the choice of categories to avoid confounding variables, such as pleasantness, animacy, or living

vs non-living objects. The categories were chosen so that naturalness or artificiality was the only commonality between them.

Table 1: Categories used for IAT by modality and naturalness

	Natural categories	Manufactured categories
Smells	Fruits	Candy
Images	Mountain	Building

After the choice of categories, the stimuli were selected based on a pre-test with 12 participants (10 females and 3 males, mean age 32 ± 7.6). Participants rated a set of 16 smells and 16 images on visual analog scales (VAS) following the dimensions of pleasantness, familiarity, arousal, and naturalness. Some dimensions were also evaluated specifically for smells (intensity) or images (sharpness, simplicity, warmth of colors, brightness, lightness). VAS varied from 1 (very unpleasant, very unfamiliar, very artificial, etc.) to 9 (very pleasant, very familiar, very natural, etc.) Participants also identified the stimuli, following one level for images and two levels for smells (smell's aromatic note, such as strawberry, apple, lemon, etc..., and category of product, such as yogurt, shampoo, fresh fruits, candy, etc. (see Dantec et al. in preparation for further description on these two levels of identification).

Based on this pre-test, stimuli were selected following three criteria:

- Naturalness differences between stimuli in natural objects categories and stimuli in human-made objects categories
- Stimuli were identified in the correct categories above the chance level
- Stimuli were not different for all the other dimensions evaluated to avoid confounding variables

Following these criteria, two smells were selected for each category (orange and apple for the fruits category, strawberry candy and bubble gum for the candies category) and four images per visual category.

For smells preparation, odorants were diluted in mineral oil. The dilutions varied between odorants and were chosen so that smells were iso-intense. 5ml of odorous solutions were put in an opaque flask of 15 ml (opening diameter 1.7 cm, height 5.8 cm), and a piece of polypropylene was rolled inside the bottle to prevent spilling and maximize odorant evaporation

2.1.3 Procedure

Participants sat comfortably in a chair, approximately 60 cm from a computer. They first completed the consent form and demographic questionnaires. They were then briefed on the test instructions. After instruction, a nasal cannula was set up to measure participants' breathing, and the software was calibrated to participants' breathing before the start.

Participants first began with the Implicit Association Task. Following Greenwald and colleagues (1998), the test was divided into 7 blocks (Table 2). Participants were first trained to categorize only pictures (block 1), then only smells (block 2). Participants then practiced categorizing both pictures and smells (block 3). The first experimental block (test block) was Block 4, with instructions identical to those in Block 3, except that participants did not receive feedback on their responses in this block. The location of the image categories on the screen then switched, and participants practiced categorizing the images with the new locations on the screen (Block 5). Participants performed training in categorizing odors and images with the new image locations in Block 6. Instructions in Block 7, and the second experimental block (test block) were identical to those in Block 6, except that participants did not receive feedback. Instructions were written on the screen before each block. Images appeared automatically on the screen, while odors were presented manually 1 cm below the participant's nose. Participants were instructed to look at the screen in front of them and not to move their heads during the presentation of the odors.

Table 2: Stimuli type and trials number for each block

Blocks	1	2	3	4	5	6	7
Status	Training	Training	Training	Test	Training	Training	Test
stimuli	Odors	Pictures	Both	Both	Images	Both	Both
trials	8	8	16	32	8	16	32

To avoid participants' fatigue, a 1-minute break was left between each block. In addition, the interval between stimuli was 7 seconds (Dematté et al., 2006; 2007), and the order of presentation was pseudorandomized so that no more than two stimuli of the same modality were presented successively. The place of the categories on the screen was counter-balanced between participants (half of them had fruit on the right corner of the screen, and the other half saw fruits category on the left corner of the screen). The order of presentation of the congruent and

incongruent block was also counter-balanced (half of the participants performed the congruent block first).

To measure reaction time, participants were asked to follow a specific breathing rhythm (Figure 1). Participants were asked to first ready themselves (screen 1), then inhale (screen 2), exhale (screen 3), and inhale again only when the odor was placed under their nose. The onset of inspiration initiated the display of categories on the screen (screen 4). Participants were instructed to categorize as fast as possible the smells or images when screen 4 appeared. For training blocks (1, 2, 3, 5, and 6) feedback (“correct” or “wrong”) appeared on the screen after their answer so that screen 4 was presented to the participants for 3 seconds, and then screen 5 appeared. For test blocks (4 and 7), screen 5 appeared as soon as the participants answered.

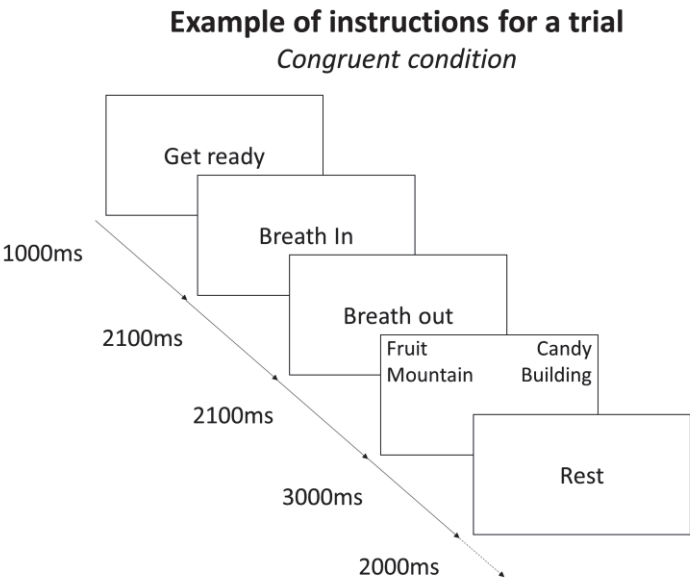


Figure 1: Example of instructions and breathing rhythm for a trial

The whole IAT lasted around 35 minutes. After the IAT, participants answered a questionnaire on the computer. They were asked to evaluate each stimulus on VAS following the dimensions of pleasantness, familiarity, arousal, and naturalness. Some dimensions were also evaluated specifically for smells (intensity) or images (sharpness, simplicity, warmth of colors, brightness, lightness). VAS varied from 1 (very unpleasant, very unfamiliar, very artificial, etc.) to 9 (very pleasant, very familiar, very natural, etc.) Participants then filled out a questionnaire to evaluate their attitude toward natural products, for three categories of products: food, personal care products, and household products (Chapter 3)

2.1.4 Reaction time measure

Measures of reaction time (RT) differed between images and smells. For images, RT was measured as the latency between the display of the images on the screen, and participants' answers (Figure 2A). For odors, RT was measured as the latency between the onset of breathing after odor presentation, and participants' responses (Figure 2B). The accuracy of RT measurements for odors depended on participants' ability to adhere to the breathing time. If participants inhaled before the end of the "exhale" instruction (screen 3), the software detected the discrepancy, and the trial was deleted.

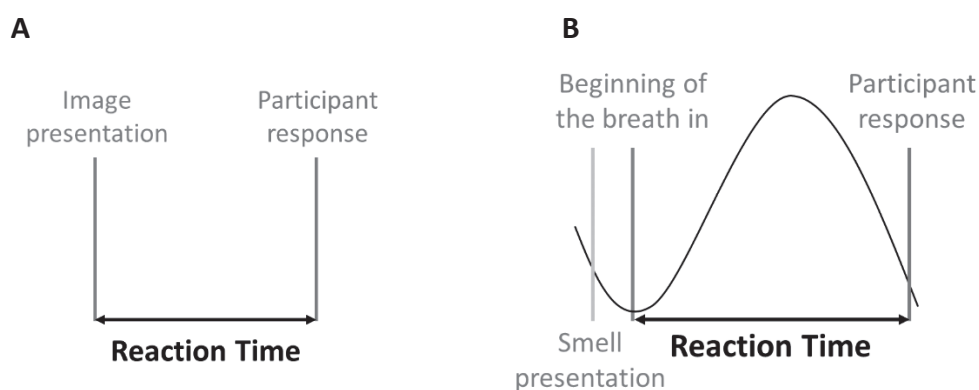


Figure 2: Measures of reaction time for images (A) and smells (B)

2.1.5 Statistical analysis

Outliers are problematic in the analysis of reaction time data because they are the result of processes that are not the ones being studied, such as the subject's inattention. These data can lower the power of statistical analysis and decrease the model fit with data of interest. However, unambiguously identifying outliers is difficult, as the distribution of outliers and data of interest can overlap (Ratcliff, 1993). As suggested by Greenwald and colleagues (1998), RTs lower than 300 ms or longer than 3000ms were discarded. In addition, another method consists of using standard deviation to trim data (Greenwald et al., 2003; Ratcliff, 1993). We thus used the criterion applied by Dematté and colleagues (2006, 2007) who first adapted the IAT method to the olfactory domain: the average reaction time was calculated for each participant for Blocks 3, 4, 6, and 7 (double categorization), and responses deviating by 2.5 standard deviations or more from the participant mean were removed from further analysis (Dematté et al., 2006).

Data without outliers were then log-transformed to shape RT distribution into a normal distribution (Greenwald et al., 1998; 2003).

Transformed data of experimental blocks (4 and 7) were then analyzed with linear mixed models (lmm). To test our hypotheses, we investigated the effect of condition (congruent vs incongruent), modality (smell vs images), and their interaction on RT. As exploratory investigations, we also added naturalness (natural vs artificial categories) as predictors, as well as order of congruent block presentation to control for order effect. RT was set as the dependent variable. Random variables (participants and stimuli) and predictors were added incrementally. After each addition of a new variable, the increase in the model's fit of the data was tested (with anova function). Errors were analyzed with generalized linear mixed models (binomial distribution), following the same procedure as for the analysis of RT.

2.2 Results

2.2.1 IAT results

The addition of participants and stimuli as random variables significantly improved the model's fit of the data (Table 3 in supplementary material), suggesting a variability of RT between participants and between stimuli. Moreover, the addition of condition (congruent vs incongruent) and modality (smells vs images) significantly improved the model's fit of the data (Table 3 in supplementary material), while the addition of condition and modality interaction, naturalness of the stimuli, order of congruent block, and interaction between the order of congruent block and condition did not improve significantly the model's fit of the data (Table 3 in supplementary material). Analysis of the final model revealed a significant effect of condition ($\chi^2(1)=5.78$, $p=.02$); as participants were faster in congruent condition ($M=903\pm413$) than in incongruent condition ($M=929\pm414$) (Figure 3A); and a significant effect of modality ($\chi^2(1)=126.9$, $p<.001$); as participants were faster to categorized images ($M=777\pm307$) than smells ($M=1064\pm459$) (Figure 3B). Moreover, evaluation of the size of the condition effect with the Cohen d (Cohen, 1988) revealed that the condition effect was small ($d=.4$) but not marginal.

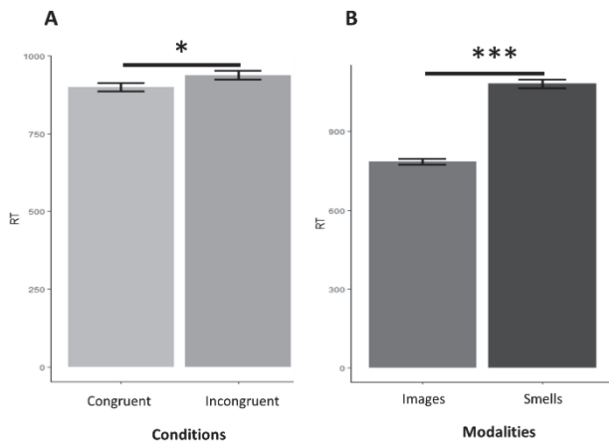


Figure 3: Effect on RT of condition (A) and modality (B) for study 1

2.2.2 Results error

The addition of participants and stimuli as random variables significantly improved the model's fit of the data, suggesting a variability of error probability between participants and between stimuli. Moreover, the addition of modality significantly improved the model's fit of the data, and a tendency appeared for the addition of naturalness of the stimuli (natural vs artificial). The addition of the condition did not significantly improve the model's fit of the data. Analysis of the final model with the three variables revealed a significant effect of modality ($\chi^2(1)=70.5$, $p<.001$), and a significant effect of stimuli naturalness ($\chi^2(1)=4.1$, $p=.04$), as participants did less mistake for images and artificial stimuli categorization, while the effect of condition was not significant ($\chi^2(1)=.3$, $p=.61$).

2.2.3 Stimuli evaluation

Evaluation of the stimuli was analyzed to investigate which variable may drive the association between natural images and smells and artificial images and smells. Each variable was set as the independent variable of a linear mixed model, with participants as random factors, and stimuli naturalness (natural vs artificial) and modality (images vs smells) as predictors.

Naturalness - As expected, we found an effect of stimuli naturalness on naturalness evaluation ($\chi^2(1)=387.6$, $p<.001$), as natural stimuli were perceived as more natural ($M=7.4\pm 2.1$) than artificial stimuli ($M=3.5\pm 2.6$). The effect of modality was also significant ($\chi^2(1)=124.6$, $p<.001$), as images were perceived as more natural ($M=6.2\pm 2.9$) than smells ($M=3.9\pm 2.8$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less natural

($M=4.2\pm 2.7$) than images of mountains ($M=8.2\pm 1.3$), and candy smells were perceived as less natural ($M=2.0\pm 1.5$) than fruit smells ($M=5.7\pm 2.5$).

Pleasantness – Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=172.0, p<.001$), as natural stimuli were perceived as more pleasant ($M=7.3\pm 1.7$) than artificial stimuli ($M=4.9\pm 2.1$). The effect of modality was not significant ($\chi^2(1)=1.8, p=.018$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less pleasant ($M=4.8\pm 2.1$) than images of mountains ($M=7.6\pm 1.6$), and candy smells were perceived as less pleasant ($M=5.2\pm 2.2$) than fruit smells ($M=6.7\pm 1.7$).

Arousal - Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=102.3, p<.001$), as natural stimuli were perceived as more arousing ($M=6.4\pm 2.0$) than artificial stimuli ($M=4.4\pm 2.5$). The effect of modality was not significant ($\chi^2(1)=2.6, p=.011$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less arousing ($M=3.9\pm 2.2$) than images of mountains ($M=6.6\pm 2.0$), but candy smells were not perceived as significantly less arousing ($M=5.2\pm 2.2$) than fruit smells ($M=6.0\pm 2.0$).

Familiarity - Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=24.2, p<.001$), as natural stimuli were perceived as more familiar ($M=6.5\pm 2.6$) than artificial stimuli ($M=5.5\pm 2.9$). The effect of modality was also significant ($\chi^2(1)=110.6, p<.001$), as images were perceived as less familiar ($M=5.2\pm 3.0$) than smells ($M=7.5\pm 1.5$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less familiar ($M=4.4\pm 2.9$) than images of mountains ($M=6.0\pm 2.8$), but candy smells were not perceived as significantly less familiar ($M=7.5\pm 1.3$) than fruit smells ($M=7.4\pm 1.5$).

Modality-specific dimensions - For smells, candy smells were perceived as more intense ($M=7.1\pm 1.9$) than fruit smells ($M=5.2\pm 1.9$; $\chi^2(1)=37.3, p<.001$). For images, images of buildings were perceived as less bright ($M=6.1\pm 1.6$) than images of mountains ($M=6.6\pm 1.7$; $\chi^2(1)=9.6, p=.002$), but no significant differences were found for the other variables (complexity, sharpness, color warmth, lightness, all $ps>.01$)

2.2.4 Attitude toward naturalness

Results yielded a significant negative correlation between the evaluation of pleasantness of candy smells and attitude toward natural personal care products ($r=-0.39, p=.02$); the more positive the attitude toward natural personal care products, the less pleasant the candy smells

were perceived. We also observed a tendency of correlation between the evaluation of naturalness of candy smells and attitude toward natural personal care products ($r=-0.31, p=.08$).

2.3 Discussion

2.3.1 Congruency effect

As expected, participants were faster in the congruent condition than in the incongruent condition, suggesting a congruency effect and thus an association between images and smells representing natural objects and/or between images and smells representing artificial objects. In addition, this result suggests that our method to measure reaction times was sensible enough to capture the facilitation effect on RTs resulting from congruency between natural images and smells. Moreover, this effect was found for both modalities, smells, and images, without any interaction between condition and modality.

In line with previous IATs conducted with images and smells (Dematté et al., 2006), participants were also faster and did fewer mistakes to categorize images than smells. Categorization of images seems thus easier than smells categorization. Smells are more ambiguous and less easily identified than images, which may explain this difference in RT and errors between modalities.

However, a question remains about the dimension underlying this association. As natural images (mountains) and smells (fruits) were perceived as more natural than artificial images (building) and smells (candy), the naturalness dimension may drive the association. However, our results also showed similar results for pleasantness, as natural images were more pleasant than artificial images, and natural smells were more pleasant than artificial smells. Pleasantness rather than naturalness might thus drive the association. The probability that arousal or familiarity were the dimensions underlying the observed association is lower, as no significant differences were observed for the arousal and familiarity dimensions between natural smells and artificial smells. Moreover, perceptual features could also drive the association. Indeed, perceptual features such as sound pitch and brightness have been shown to mediate crossmodal correspondences between sounds and colors (see Spence 2011 for a review about crossmodal correspondences). The association between natural images and smells and/or between artificial images and smells might thus be mediated by a correspondence between intensity and brightness. However, as artificial smells were perceived as more intense than natural smells, but artificial images were perceived as less bright than natural images, this hypothesis may

appear as less probable than the mediation through naturalness or pleasantness dimensions. Further investigations are thus needed to better understand the dimension underlying the observed association.

2.3.2 Attitude toward naturalness and perception of stimuli

In line with Michel and colleagues (2019) results, we found a tendency of a negative correlation between attitude toward naturalness and evaluation of the naturalness of candy smells. Results also showed a negative correlation between the evaluation of pleasantness of candy smells and attitude toward natural personal care products. Participants with the most positive attitude toward natural personal care products found on average candy smells less pleasant. As attitude is an evaluative disposition, i.e. an evaluation of naturalness on a continuum from favorable to unfavorable (Albarracin & Shavitt, 2018), it may not seem surprising that participants with a favorable attitude toward natural products perceived artificial smells as less pleasant. However, results from previous studies on this point were inconclusive (Herz, 2003). Surprisingly, the correlations were restrained to candy smells and attitude toward natural personal care products, although no obvious link appeared between candy and personal care products. Further research may bring new elements to better understand these correlations.

In summary, our first study provided interesting results and revealed a congruency effect, with participants being faster in the congruent condition than in the incongruent condition. However, some questions remain, especially the dimension underlying the observed association. Therefore, the previous design was replicated with a new sample in order to confirm our results and further understand the observed congruency effect. In addition, the study was conducted in a new cultural area to allow for greater generalization of our results.

3. Study 2

3.1 Method

3.1.1 Participants

33 American participants were recruited for this study, 25 females and 8 males, with 7 participants being between 18 and 24 years old, 7 being between 25 and 34 y/o, 4 being between 35 and 44 y/o, and 7 being between 45 and 54 y/o, and 8 being between 55 and 64 y/o. All the participants declared having no olfactory, visual, or motor impairment.

3.1.2 Stimuli

The stimuli and categories were the same as for study 1. A pre-test was first conducted (N=15, 10 female and 4 males, mean age 36 ± 11.0) with American participants to ensure that fruit smells were perceived as more natural than candy smells. Among these 14 participants, 10 participants (66%) ranked the two fruit smells as more natural than candy smells, and 5 of them (33%) ranked chewing-gum smell in the two most natural smells.

3.1.3 Procedure

The procedure, measures, and statistical analysis were the same as those of study 1.

3.2 Results

3.2.1 IAT results

The addition of participants and stimuli as random variables significantly improved the model's fit of the data (Table 4 in supplementary material), suggesting a variability of RT between participants and between stimuli. Moreover, the addition of modality (smells vs images) and the interaction between condition and the order of congruent block presentation significantly improved the model's fit of the data (Table 4 in supplementary material), while the addition of condition, condition, and modality interaction, the naturalness of the stimuli, and order of congruent block presentation did not improve significantly the model's fit of the data (Table 4 in supplementary material). Analysis of the final model revealed a significant effect of modality ($\chi^2(1)=222.8$, $p<.001$); as participants were faster to categorize images ($M=777 \pm 307$) than smells ($M=1064 \pm 459$) (Figure 4A), and a significant interaction between condition (congruent vs incongruent) and the order of congruent block presentation (first or second) ($\chi^2(1)=7.0$, $p=.008$, Figure 4B). Moreover, although not significant, the evaluation of the size of the condition effect with the Cohen d (Cohen, 1988) revealed that condition effect was small ($d=.2$) but not marginal. Further investigations revealed that the effect of condition on RT was significant for the group of participants who first categorized the stimuli in the congruent block ($\chi^2(1)=6.6$, $p=.01$), while its effect was not significant for the group who first categorized the stimuli in the incongruent block ($\chi^2(1)=1.6$, $p=.020$, figure 5).

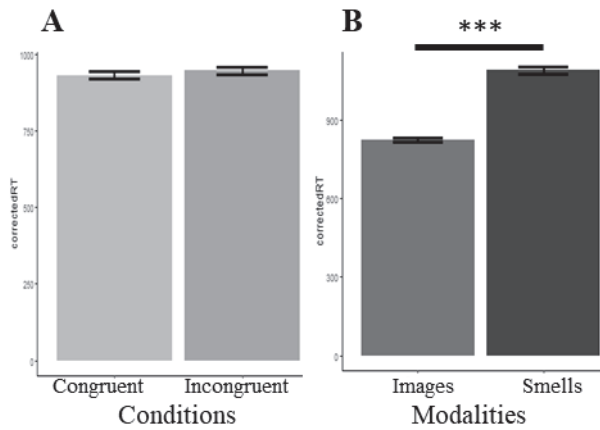


Figure 4: Effect on RT of condition (A) and modality (B) for study 2

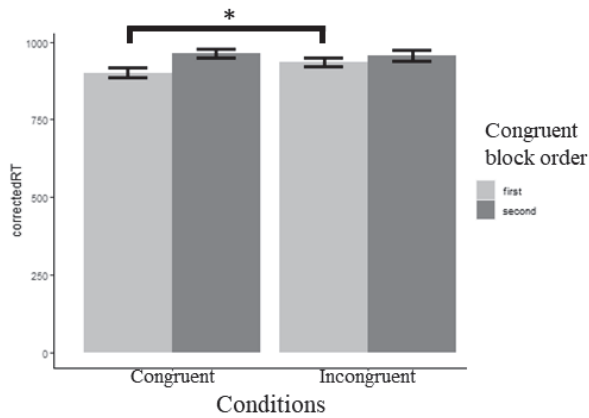


Figure 5: Interaction between condition and order of presentation of congruent block

3.2.2 Errors result

The addition of participants and stimuli as random variables significantly improved the model's fit of the data, suggesting a variability of error probability between participants and between stimuli. Moreover, the addition of modality significantly improved the model's fit of the data, while the addition of condition or naturalness of the stimuli did not significantly improve the model's fit of the data. Analysis of the final model with the three variables revealed a significant effect of modality ($\chi^2(1)=134.6$, $p<.001$), as participants did fewer mistakes for images categorization, while the effects of stimuli naturalness ($\chi^2(1)=.7$, $p=.40$) and condition were not significant ($\chi^2(1)=2.2$, $p=.14$).

3.2.3 Stimuli evaluation

As for study 1, the evaluation of the stimuli was analyzed to investigate which variable may drive the association between natural images and smells and artificial images and smells. Each variable was set as an independent variable of a linear mixed model, with participants as random factors, and stimuli naturalness (natural vs artificial) and modality (images vs smells) as predictors.

Naturalness - As expected, we found an effect of stimuli naturalness on naturalness evaluation ($\chi^2(1)=1120.9, p<.001$), as natural stimuli were perceived as more natural ($M=8.1\pm1.5$) than artificial stimuli ($M=2.7\pm2.1$). The effect of modality was also significant ($\chi^2(1)=7.2, p=.007$), as images were perceived as more natural ($M=5.6\pm3.5$) than smells ($M=5.1\pm2.7$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less natural ($M=2.4\pm2.0$) than images of mountains ($M=8.7\pm1.0$), and candy smells were perceived as less natural ($M=3.2\pm2.0$) than fruit smells ($M=7.0\pm2.2$).

Pleasantness - Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=110.4, p<.001$), as natural stimuli were perceived as more pleasant ($M=7.3\pm1.8$) than artificial stimuli ($M=5.3\pm2.3$). The effect of modality was not significant ($\chi^2(1)=3.9, p=.05$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less pleasant ($M=4.8\pm2.3$) than images of mountains ($M=7.5\pm1.8$), but candy smells were not perceived as significantly less pleasant ($M=6.2\pm2.1$) than fruit smells ($M=6.9\pm1.8$).

Arousal - Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=106.6, p<.001$), as natural stimuli were perceived as more arousing ($M=6.5\pm2.1$) than artificial stimuli ($M=4.4\pm2.4$). The effect of modality was not significant ($\chi^2(1)=0.6, p=.43$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less arousing ($M=3.9\pm2.4$) than images of mountains ($M=7.0\pm2.0$), but candy smells were not perceived as significantly less arousing ($M=5.5\pm2.0$) than fruit smells ($M=5.7\pm2.0$).

Familiarity - Analysis of the model showed an effect of stimuli naturalness ($\chi^2(1)=34.9, p<.001$), as natural stimuli were perceived as more familiar ($M=7.4\pm1.9$) than artificial stimuli ($M=6.3\pm2.4$). The effect of modality was not significant ($\chi^2(1)=0.56, p=.46$), as images were not perceived as significantly less familiar ($M=6.8\pm2.4$) than smells ($M=6.9\pm1.8$). Post-hoc tests with Tukey correction revealed that images of buildings were perceived as less

familiar ($M=6.0\pm 2.6$) than images of mountains ($M=7.6\pm 1.9$), but candy smells were not perceived as significantly less familiar ($M=6.8\pm 1.9$) than fruit smells ($M=7.1\pm 1.8$).

Modality-specific dimensions - For smells, candy smells were perceived as more intense ($M=6.2\pm 1.9$) than fruit smells ($M=5.3\pm 2.1$; $\chi^2(1)=9.1, p=.003$). For images, images of mountains were perceived as more complex ($M=5.3\pm 2.6$) than images of mountains ($M=4.6\pm 2.7$; $\chi^2(1)=7.5, p=.006$), but no significant differences were found for the other variables (brightness, sharpness, color warmth, lightness, all $p>.01$)

3.2.4 Attitude

Results yielded a significant positive correlation between the evaluation of pleasantness of images of mountains and attitude toward natural personal care products ($r=.34, p=.05$); the more positive the attitude toward natural personal care products, the more pleasant the images were perceived.

3.2.5 Comparison FR-US

Lastly, the evaluation and performances of the two cultural samples were compared. Comparisons of RT between countries revealed a significant difference ($t(6532)=-3.97, p<.001$), with French participants being on average faster ($M=961\pm 454$) than American participants ($M=1002\pm 415$). However, the effect size of the difference was very small ($d=.10$), suggesting that this effect is marginal.

Then, the evaluation of the stimuli was compared between samples. Analysis revealed that the effect of country on naturalness evaluation was not significant ($\chi^2(1)=.01, p=.92$), but the interaction of country with stimuli category was significant ($\chi^2(3)=97.7, p<.001$). Post-hoc tests showed that on average, American participants perceived the images of buildings as less natural ($M=2.4\pm 2.0$ vs $M=4.2\pm 2.7, b=1.8, t(772)=7.9, p<.001$), and the smells of candies ($M=3.2\pm 2.2$ vs $M=2.0\pm 1.5, b=-1.2, t(767)=-3.8, p=.004$) and fruits ($M=7.0\pm 1.7$ vs $M=5.7\pm 2.5, b=-1.3, t(767)=-3.9, p=.003$) as more natural than French participants. As for naturalness, the effect of country on pleasantness evaluation was not significant ($\chi^2(1)=1.4, p=.23$), but the interaction of country with stimuli category was significant ($\chi^2(3)=8.5, p=.04$). Post-hoc tests showed that on average American participants perceived the smells of candies as more pleasant than French participants ($M=6.2\pm 2.1$ vs $M=5.2\pm 2.2, b=-1.0, t(768)=-3.1, p=.04$). For familiarity, the effect of country on familiarity ratings was significant ($\chi^2(1)=25.6, p<.001$), as well as the interaction

between country and stimuli categories ($\chi^2(3)=43.2$, $p<.001$). Post-hoc tests revealed that American participants found images of buildings ($M=6.0\pm 2.6$ vs $M=4.4\pm 2.9$, $b=-1.4$, $t(768)=-5.5$, $p<.001$) and mountains ($M=7.6\pm 1.9$ vs $M=6.0\pm 2.8$, $b=-1.5$, $t(768)=-5.7$, $p<.001$) more familiar than French participants. Last, the effect of country on arousal was not significant ($\chi^2(1)=.3$, $p=.6$), and the interaction between country and stimuli category was not significant as well ($\chi^2(3)=3.4$, $p=.3$).

3.3 Discussion

3.3.1 Congruency effect and order of presentation

Contrariwise to our first study, analysis did not yield a significant effect of condition. However, results revealed an interaction between the order or presentation of the congruent block and condition variable. Further analysis showed a significant effect of condition for the group who had to categorize stimuli in the congruent block first, while this effect was not significant for the group who had to categorize stimuli in the incongruent block first. This interaction may be due to the difficulty that participants faced when the association between images and key changed. Indeed, as Nosek (2005) pointed out, order of conditions presentation is one of the most common issues for IAT (Nosek, 2005). The authors noted an interference between the order of conditions presentation and the congruency effect: the magnitude of the congruency effect is greater when the congruent condition is presented first than when it is presented after the incongruent condition. The author suggested that this interference may be due to the effort resulting from task-switching. Therefore, additivity may occur in the first group between the congruency effect and the difficulty of changing instructions, whereas these effects may cancel each other out in the other group. Surprisingly, this interaction was not significant in the first study.

3.3.2 Confounding variables

Interestingly, naturalness evaluation was different between natural images and artificial images and between natural smells and artificial smells, but the difference in pleasantness evaluations was significant only between natural images and artificial images. In light of this result, the hypothesis that pleasantness may drive the association between natural images and smells and/or between artificial images and smells appears less probable. As for the French sample, differences in arousal and familiarity were significant only between natural images and artificial

images. In addition, the difference in brightness between natural images and artificial images was not significant for the American sample although it was significant for the French sample.

4. General discussion

Our results revealed a significant effect of condition in the French sample, suggesting an association between smells and images representing natural kinds, and/or between smells and images representing artifacts. The results are less clear for the American sample, as the effect of condition appeared only for the group exposed to the congruent condition first. Similar effects of the order have been found in previous IATs (Nosek, 2005). The authors suggest that this order effect is due to the difficulty for participants to switch instructions between the two experimental conditions. Increasing the number of trials in blocks 5 and 6 (training for new instructions) could reduce this order effect and reduce the interference between the congruency effect and the order of block presentation. However, attention must also be paid to participant fatigue, as this task is demanding, especially for smell categorization.

Nevertheless, the significant interaction between conditions and order of presentation of congruent block let suppose that the congruency effect occurs for both groups, but was hidden by the order effect in the group who was exposed to the incongruent condition first. These results suggest that naturalness is a dimension that cuts across the sensory modalities, visual naturalness and olfactory naturalness sharing the same meaning: a stimulus is natural because it represents a natural object. Naturalness would thus be a cognitive property modulated by the stimulus representation. This assumption is in line with previous research which finds an effect of smells' identification on perceived naturalness of smells' (Chapter 4, study 3). However, this study also found some correlations between naturalness perception and perceptual features of smells such as intensity perception. Therefore, although the cognitive dimension seems to play a role in naturalness perception, it may not be the only dimension accounting for naturalness evaluation.

In addition, the pleasantness dimension was found to be confounding with the naturalness dimension in the French sample. Pleasantness as naturalness was thus suspected to drive the found association. Moreover, previous results found a strong connection between naturalness and pleasantness in olfactory perception, as the most natural smells are also the most pleasant (Herz, 2003; Apaolaza and colleagues, 2014). Furthermore, valence is a common confounding variable in IAT (De Houwer et al., 2009). However, the pleasantness difference was not

significant in the American sample, suggesting that the congruency effect found in the group first exposed to the congruent block might not be mediated by the pleasantness dimension, reinforcing the hypothesis that naturalness drove this association. Follow-up research is needed to tackle this issue. Especially, the use of more neutral images (especially for pleasantness and arousal dimensions) would be useful to better understand the dimension underlying the observed association, especially for the issue of valence and naturalness overlapping. At the same time, the use of new categories may extend our result, as we can not exclude that the observed association was due to the association between mountains and fruits and/ or between buildings and candies rather than to the naturalness of the objects represented by the stimuli.

In line with our second objective, observation of a congruency effect, at least in the French sample, suggests that the method followed for delivery of smells and measure of reaction time is sensible enough for IAT. In addition, although the mode of delivery of stimuli was different between smells and images, the interaction between modality and condition was not significant. Therefore, this difference does not seem to affect the congruency effect. This method opens up new possibilities for measuring reaction times, in particular the use of complex odorants that were not optimal for protocols using an olfactometer.

Analysis of the relationship between attitude toward natural products and perception of smells yielded divergent results between the two samples. In the French sample, we found a negative correlation between the evaluation of pleasantness of candy smells and the attitude toward natural personal care products, while we found a positive correlation between the evaluation of pleasantness of images of mountains and attitude toward natural personal care products in the American sample. Although it seems that attitude toward natural personal care products is related to the perception of the naturalness of product categories and the pleasantness of stimuli, the category of stimuli affecting varied between samples. Investigations of the effect of attitudes and beliefs on the perception of naturalness may require a bigger sample size to better understand the relation between these variables.

Last, our results bring some new elements to understand the relationship between naturalness and perceptual dimensions. In line with previous studies, we found that natural stimuli were also more pleasant than artificial ones (Herz, 2003; Apaolaza et al., 2014; Padulo et al., 2018), although this divergence was restrained to visual stimuli in the American sample. Moreover, for both samples, images of buildings were perceived as less familiar and less arousing than

images of mountains, while the difference in familiarity and arousal between smells categories was not significant. These results are consistent with previous research on the visual modality which found a positive relationship between arousal, familiarity, and naturalness (Padulo et al., 2018). For the olfactory domain, previous studies observed a correlation between the arousal dimension and the naturalness of smells, although these dimensions do not seem to be related in our data. Moreover, for familiarity, results are in contradiction with Herz (2003) results who found that smells categorized as natural were also rated as more familiar. The difference in intensity perception was also found between smells categories for both samples, while the dimension differing between images categories was inconsistent across samples. This inconsistency illustrates the variability of stimuli evaluation between samples. Indeed, our results showed differences in the evaluation of stimuli between samples, for naturalness, pleasantness, and familiarity dimensions.

5. Conclusion

The aim of the studies reported here was twofold. First, the objective was to investigate the crossmodal meaning of naturalness with an implicit association task. Analysis of our data revealed a congruency effect in the French sample, and one of the two groups in the American samples. These results suggest that naturalness is indeed a dimension that cuts across the sensory modalities. However, two limitations prevent us from drawing any conclusions at this time. The first one is the issue of the confounding variables, and especially the overlapping between pleasantness and naturalness dimensions. Indeed, in the French sample, natural stimuli were more natural but also more pleasant than artificial stimuli, which leaves it unclear which dimensions underline the observed association. In the American sample, the pleasantness difference was limited to visual stimuli, suggesting that naturalness may drive the associations. Moreover, a second issue is the problem of the order of block congruency and condition interaction, although it was observed only for the American sample. Indeed, in this sample, the congruency effect was observed only for the group who performed the congruent block first. Therefore, although promising, our results need to be confirmed and extended with new results to tackle these two issues of confounding variables and order interaction.

Our second objective was to adapt the method developed by Manesse and colleagues (2020) for priming task to the implicit association task. This objective was mainly motivated by the desire to avoid the use of an olfactometer to deliver the odors. Observation of the congruency

effect and the absence of interaction between modalities and conditions suggest that this method is reliable for psychometric measures and IAT.

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Supplementary material

Table 3: Model comparison of effects of variables on reaction time for study 1 (French sample)

Sampling Units		N Subjects =34 ; N stimuli=12							
Model	Fixed effects added	Random effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
Random	-	Intercepts	Intercepts	-2347	-2325	1177	4		
1	Conditions	Intercepts	Intercepts	-2351	-2323	1180	5	1	5.8 *
2	Conditions + Modality	Intercepts	Intercepts	-2377	-2344	1195	6	1	28.4 ***
3	Conditions + Modality + Conditions:Modality	Intercepts	Intercepts	-2375	-2337	1195	7	1	0.43
4	Conditions + Modality + Conditions:Modality + stimuli naturalness	Intercepts	Intercepts	-2374	-2329	1195	8	1	0.20
5	Conditions + Modality + Conditions:Modality + stimuli naturalness + block order	Intercepts	Intercepts	-2373	-2323	1196	9	1	1.6
Final model	Conditions + Modality + Conditions:Modality + Stimuli naturalness + Block order + Conditions:Block order	Intercepts	Intercepts	-2372	-2317	1196	10	1	0.93

Table 4: Model comparison of effects of variables on reaction time for study 2 (American sample)

Sampling Units		N Subjects =33 ; N stimuli=12							
Model	Fixed effects added	Random effects		Model fit				LRT test	
		Subjects	Odorants	AIC	BIC	LL	df	df	X ²
Random	-	Intercepts	Intercepts	-2577	-2555	1293	4		
1	Conditions	Intercepts	Intercepts	-2576	-2548	1293	5	1	0.62
2	Conditions + Modality	Intercepts	Intercepts	-2608	-2575	1310	6	1	33.9 ***
3	Conditions + Modality + Conditions:Modality	Intercepts	Intercepts	-2606	-2568	1320	7	1	0.68
4	Conditions + Modality + Conditions:Modality + stimuli naturalness	Intercepts	Intercepts	-2604	-2561	1310	8	1	0.002
5	Conditions + Modality + Conditions:Modality + stimuli naturalness + block order	Intercepts	Intercepts	-2603	-2554	1311	9	1	0.60
Final model	Conditions + Modality + Conditions:Modality + Stimuli naturalness + Block order + Conditions:Block order	Intercepts	Intercepts	-2608	-2553	1314	10	1	6.95 **

Interim Summary Chapter 5

The results of our fourth study confirm the previous findings. First, the evidence of the congruence effect in the French panel, and for one of the two groups in the American panel, suggests an association between odors and images as a function of the naturalness of the object they represent. In addition, the evaluation of the stimuli also suggests a positive relationship between naturalness and pleasantness. As with Study 3, these results support our hypotheses 2 and 3.

This study concludes our experimental phase. We will discuss the different contributions of the research conducted in relation to our hypotheses, their limitations and the perspectives of our work in the next chapter.

Part C – General Discussion

Chapter 6- Findings & Perspectives

The great technical and cultural changes that occurred during the 20th century have deeply influenced the perception of naturalness (Vogt, 2007). Although it was depreciated for a long time in the history of Western countries, the attitude toward naturalness has become more positive (Román et al., 2017; Rozin et al., 2004; Schösler et al., 2013). Several factors related to the sensory attributes of objects, including visual (Deliza et al., 2003), tactile (Labbe et al., 2013), and gustatory (King & Duineveld, 1998), have been identified as modulating perceived naturalness. However, during our review of the factors modulating the perception of naturalness, we observed that the factors underlying the perceived naturalness of odors remain unclear.

Therefore, an important aim of the present thesis was to clarify the concept of naturalness for olfaction. To reach that objective we dealt with several problems: the polysemy of naturalness, the ambiguity of odors, and the inter-individual variability regarding both the way to define naturalness or the way to perceive it in the olfactory domain. After specifying of naturalness (Chapter 1), we sought to determine the relevant levels of analysis for studying the perception of odor naturalness (Chapter 2). A short review of the literature on olfactory perception allowed us to isolate three relevant levels of analysis that could contribute to the naturalness of odors: the physical source, perceptual and cognitive levels. Our main objective was therefore to study the contributions of the physical source, perceptual and cognitive levels (through the identification process in particular) to the perception of the naturalness of odors.

Our different experiments (part B), aimed to bring new elements of knowledge clarifying the implications of these different levels in the perception of the naturalness of odors. Note that the question of inter-individual and cultural variabilities in the perception of naturalness was also considered in these experimental studies. In this chapter we discussed the different outcomes of these experimental phases that we summarize below.

1. The level of the physical source

Our first hypothesis was that: *The naturalness of the physical source influences the perception of the naturalness of smells.*

This hypothesis was based on the observations that 1) physical sources and the blend of volatile molecules they emit shape odors processing 2) humans have a great ability for smell discrimination, and 3) that some human transformations also affect odors (e.g. cooking), making human influence perceptible through the olfactory modality. Therefore, we assumed that differences in the naturalness of the physical source would result in differences in the perceived naturalness of smells. A smell coming from a natural physical source was expected to be perceived as more natural than a smell coming from a manufactured physical source.

In Study 2 (chapter 4) on the olfactory attributes and colors associated with naturalness, we observed that participants associated with the term “natural odor” some words referring to the physical source of smells and the way it was produced. For example, participants associated with “natural odor” words like “without additives”, “unprocessed”, or also “extracted from a flower”, while they associated words like “fake”, “artificial”, and “human-made”, with “unnatural odor”. These findings suggested that the naturalness of an odor depends on the production process of the physical source of the odor: the less transformed the source, the more natural the smell. However, these results came from expectations about naturalness rather than from the evaluation of smells as no odors were provided to participants.

In Study 3 (chapter 4) on the perceptual and cognitive factors modulating the naturalness of smells, we thus investigated the perceived naturalness of smells for different odorants. Among our stimuli, we were especially interested in studying the perception of naturalness between natural and non-natural flavorings. Based on French and European regulation (Regulation (EC) No 1334/2008 of the European Parliament, 2008), flavorings are natural when the molecules are extracted from a natural source rather than obtained through chemical synthesis. Moreover, non-natural flavorings have been singled out because they have been presented as altering the perception of naturalness of products, while natural flavorings do not (Murley & Chambers, 2019). Nevertheless, in Study 3, no significant difference in the ratings of the naturalness of smells appeared between natural and non-natural flavorings. These observations are consistent with Herz’s study (2003), in which categorization of naturalness of natural complex odorants (e.g. Lemon oil) or monomolecular synthetic odorants (e.g. Citral) was at chance level.

In summary, our **first hypothesis was not supported by our experimental data**. However, exploration of the effect of the naturalness of the physical source **was limited to the comparison of naturalness perception between smells coming from extracted molecules and synthetic molecules**. In addition, in Study 3, the **range of odorant was limited to strawberry odors**. **Comparison of smells coming from natural entities (e.g. a fresh strawberry) and flavorings** would an **interesting perspective** to investigate also how differences in the chemical complexity of the source may influence naturalness perception, as well as inclusion of **more diverse smells** (e.g. strawberry and other fruits, but also other natural entities and manufactured objects).

2. The perceptual level

Our second hypothesis was that: *the perceptual features of the stimuli influence the perceived naturalness of smells*

More specifically, considering previous results on the association of naturalness with pleasantness, familiarity and arousal, we expected these dimensions to be associated with smells' naturalness. Moreover, the intensity being one of the prominent dimensions of odors perception (David et al., 1997), the intensity was also expected to have an effect on naturalness perception.

Our results support this hypothesis. In Study 2 (Chapter 4) on the olfactory attributes and colors associated with naturalness, participants spontaneously associated perceptual features with the terms “natural odor” or “unnatural odor”. Indeed, “natural odor” was associated with pleasantness and lightness, while “unnatural odor” was associated with unpleasantness and strong intensity. Some spontaneous association may also refer to trigeminal sensations, although the terms associated are ambiguous. Indeed, “unnatural odor” was associated with pungency and “natural odor” with smoothness and freshness. In addition, participants were asked to rate the expected intensity of natural products’ smell. The results showed that the expected intensity of smells of natural products was moderate, with little variation between products, the strawberry alone having a slightly stronger expected odor. However, these results were based on participants’ expectations about features of natural or unnatural smells. Therefore, we aimed in a follow-up study at bringing new elements to support these results with the evaluation of real smells.

In Study 3 (chapter 4), participants were thus asked to smell 33 different odorants, and to evaluate on continuous scales the perceived smells following 6 dimensions: pleasantness, edibility, intensity, arousal, familiarity and naturalness. To limit interindividual variability in the interpretation of each dimension, a short definition of each dimension was provided. Results revealed a positive effect of pleasantness and edibility, and a negative effect of arousal and intensity on naturalness ratings.

In Study 4 (chapter 5), the evaluations of stimuli following the pleasantness, arousal, familiarity, and naturalness dimensions also shed light on perceptual factors related to naturalness perception. As in the two previous studies, natural stimuli were perceived as more pleasant than artificial stimuli, except for the American panel, for which no difference has been observed in pleasantness between fruits (natural) and candy (artificial) odors. In both samples, natural images (mountains) were perceived as more familiar and arousing than artificial images (buildings), but the differences were not significant for olfactory stimuli.

Interestingly, for the pleasantness dimension, our results are consistent between our three studies, but also with previous research. Indeed, previous research found that smells categorized as natural were also perceived as more pleasant (Apaolaza et al., 2014; Herz, 2003). This relationship between pleasantness and naturalness has also been found beyond the olfactory domain, as natural products are generally more appreciated than non-natural products (Rozin et al., 2004; Romàn et al., 2017). This connection between naturalness and pleasantness may be grounded in the attitude of participants toward naturalness. Most consumers have a positive attitude toward naturalness (Romàn et al., 2017), and therefore associate a positive valence with natural entities. In line with this assumption, we found a positive correlation between attitude toward natural personal care products and pleasantness of artificial smells. However, observed correlations between attitude and pleasantness were limited to a category of product (personal care products) and a category of stimuli (candy for French sample, and buildings for American sample). This limitation to a category of product and some categories of stimuli might be due to limited samples (N=34 for French sample and N=33 for American sample).

However, two elements should be further discussed about the correlation between pleasantness and naturalness. The first one is the directionality of the relationship between these two dimensions. Indeed, we may wonder if natural smells are pleasant because they are natural or if they are natural because they are pleasant, or if a third dimension underlines the relation

between these two dimensions. The results of our third and fourth studies does not allow us to draw any conclusion regarding this question. Apaolaza and colleagues (2014) found a halo effect of naturalness on pleasantness: manipulating naturalness evaluation by giving information to participants also modulates pleasantness ratings. Herz (2003) found a similar result, as information about smells naturalness increased pleasantness ratings. Therefore, we may suspect that naturalness modulates pleasantness ratings rather than the reverse effect.

Another element should be discussed. In Studies 3 and 4, as well as in the study of Apaolaza and colleagues (2014), the smells were limited to pleasant smells. The observed relationship between pleasantness and naturalness may thus be restricted to pleasant smells. Moreover, it is not so difficult to find examples of natural but unpleasant odors (a quick look into the world of body odors and the odors of decaying entities can provide us with a good number of examples). Moreover, although marginal statistically, we observed in Study 2 that some American participants associated negative adjectives with natural smells (e.g. "yucky", "stinky", "musty", or "rotten"). In addition, Herz (2003) observed that pleasant smells were perceived as more pleasant when presented as natural, but the pleasantness of unpleasant smells was not modulated by information about odorants' naturalness. Thus, in future research, the relation between naturalness and pleasantness should be investigate by including unpleasant natural and artificial smells.

Another dimension that seems to be especially important for smells' naturalness is intensity. Indeed, we observed an association between intensity and naturalness of smells in Study 2 and Study 3. As with the pleasantness dimension, further research would allow to better characterize the nature of the relationship between both variables. For example, by offering the same odorant at different levels of intensity, we could test whether the intensity of an odor affects the perception of its naturalness. In addition, as with pleasantness, the negative effect of intensity may be limited to certain odors. Indeed, natural entities provide examples of objects with strong odors (e.g. spices, such as cinnamon or cloves) as well as entities with more subtle odors (e.g. wild chamomile). Therefore, the relationship between intensity and naturalness is not obvious, nor does the explanation for the observed negative effect of intensity on perceived naturalness. This effect may be limited to the context of consumer goods and processed food. Indeed, because many products and processed foods are flavored or scented, consumers may associate natural products with less flavored or scented products, and thus with lower intensity than non-natural products. The relationship between naturalness and odor intensity should therefore be

studied beyond the domain of consumer goods, notably by including natural entities (e.g. wild plant odors) as stimuli.

Along our studies, our data did not reveal clear associations between naturalness and familiarity or arousal. Indeed, naturalness of smells and familiarity were not related neither in Study 3 nor in Study 4. In the literature, the relation between familiarity and naturalness is also inconsistent between studies. In Herz study (2003), natural smells were perceived as more familiar than artificial ones. In the visual domain, natural food was found to be more familiar than transformed food in Padulo et al. study (2018), but not in Foroni and Rumiati study (2013). Furthermore, as discussed in chapter 1 part 1 of the current thesis, naturalness definition is sometimes related to familiarity, the entities or behavior being natural because familiar. Ambiguity in the definition of naturalness may thus introduce variability in the relation between naturalness and familiarity. Providing definition of naturalness to participants, as in Study 3, appears thus necessary to reduce this ambiguity. For the arousal dimension, we observed a negative relationship between arousal and naturalness. To our knowledge, no study has ever examined this relationship. In the visual domain, the evidence is also sparse. Therefore, more data are needed before drawing any conclusion on the relationship between these dimensions.

In a nutshell, our studies on the perception of naturalness of odors have highlighted the relationships of perceived naturalness with perceptual dimensions, and especially with intensity and pleasantness. However, due to **limitation** in our **stimuli set** (no unpleasant smells) or in **our designs** (no manipulation of intensity dimension), a series of **perspectives** involving **unpleasant and very natural odorants** or **intensity modulation** have been identified.

Moreover, another perspective concerns the question of the influence of perceptual dimensions on naturalness perception in other sensory modalities. In the visual domain, where object identification is easy and unambiguous (in most cases at least), naturalness has been assessed primarily on the basis of what the images represent (e.g. a fruit, Joseph, 2001). However, as with odors, the perceptual dimension could also influence the assessment of naturalness. For example, it can be expected that highly edited photographs (e.g., very bright) would be perceived as less natural than unedited photographs. This hypothesis is mainly based on observations under experimental conditions. Indeed, in the IAT paradigm several participants asked whether they should evaluate the naturalness of the image or of the object represented by

the image, putting forward the relevance of the dissociation between the medium of the representation (the image) and its representational content (the mountain represented on the image). The present investigation of naturalness in the olfactory domain has thus led to distinctions that could pave the way for further research on naturalness in other sensory modalities.

3. The cognitive level

Our third hypothesis was that: *the evaluation of naturalness varies with the identification of smells*

The semantic label associated with the smell through the identification process has been found to modulate smell perception, especially for pleasantness and intensity dimensions. Moreover, as semantic labels refer to an object of the world varying in their naturalness, we expected the perceived naturalness of the smells to vary as a function of identification.

Our results partly support this assumption. First, the results from Study 2 (chapter 4) pointed out the ambiguity between the physical source and identification in the assessment of smells naturalness. Indeed, some participants associated examples of natural kinds with “natural odor” term, such as flowers or plants, while examples of manufactured objects like hydrocarbons or consumer goods were associated with “unnatural odor” term. However, based on these responses, it was not possible to determine if a natural smell is a smell emitted by a flower or smelling like a flower.

Therefore, we explored more in-depth the cognitive factors that could sustain smells' perception of naturalness in two follow-up studies. In Study 3 (chapter 4), we investigated the effects of two cognitive factors on naturalness perception: identification and attitudes. The effect of attitude was inconclusive for this study. However, results revealed an effect of identification. Smells identified as natural entities (e.g. fresh fruits) were on average evaluated as more natural than smells identified as manufactured objects (e.g. candies), regardless of the actual naturalness of the odorant. Moreover, the participants' evaluation of the naturalness of product categories somewhat predicts the naturalness of smells identified within these categories. Taken together, these results suggest that the naturalness of smells is related to the identification of odors.

In addition, in Study 4 on the associations between natural images and natural smells (chapter 5), we observed congruency effects (i.e. between images and smells based on the naturalness of the object represented by the stimuli, at least for the French sample). Smells and visual images representing natural entities were associated, as well as smells and visual images representing manufactured objects. Thus, naturalness might be evaluated based on stimulus identification (i.e. it is an image of mountain or a smell of fruit). In addition, we observed in this study a correlation between the attitude toward natural personal care products and pleasantness evaluation of candy smells.

These results are consistent with each other and highlight a relationship between identification and the naturalness of odors. The association of an object to the smell through identification (i.e. it smells like a fresh strawberry) might thus, at least partly, determine the perception of naturalness of this smell. These results are in line with previous evidence suggesting a cognitive modulation of smell perception by semantic labels associated (Herz et al., 2001; Herz, 2003, De Araujo et al., 2005; Djerdjovic, 2008, Manescu, 2014).

However, one question in particular remains: does the source name recalled by the identification modulate the naturalness of the odor, or does the assessment of the naturalness of the odor lead to the identification of the odor? Our results do not provide an answer to this complex question. In Study 3, we did not provide labels to participants, but we observed their choices of categories matching the odors. Moreover, in this study, participants were asked to evaluate smells' naturalness before identifying them. In Study 4, although we provided a label, we did not compare their evaluation with and without labels. Therefore, the effect of labels on the naturalness perception of smells has not been specifically tested.

On the one hand, participants have difficulty naming odors, even when they are familiar (Cain & Krause, 1979; Engen, 1987). In addition, identification, i.e. the association of a name or semantic reference to an odor, is different from odor recognition, which comes from accessing the memory system that stores information about previous occurrences of the odor (Stevenson & Wilson, 2007). Although the recall of smells' names is difficult, recognition of smells is far better. Smells associated with significant real-life experiences (episodic memories) can be recognized long-time after having been smelled (Engen & Ross, 1973). Moreover, recall of smell memories in their context may lead to the recall of the properties of the object with which they were associated. This latter element might explain why some odors are for example

sometimes described as sweet, although sweet is a taste. Evidence suggested that retronasal exposition to unfamiliar odors with sucrose leads to an increase in the perception of sweetness of the smells when presented orthonasally (Stevenson et al., 1998). Co-exposition of two smells also results in the association of their properties (Stevenson, 2001; Stevenson et al., 2005). After exposition to binary odor mixtures (e.g. cherry and mushroom), participants associated the properties of a smell with the other smell (mushrooms are smelling more cherry-like after exposition to the mixture, Stevenson et al., 2005). The same effect might occur for naturalness, even in the absence of smell names. A smell might be perceived as artificial because statistically co-occurring with an artificial object, even ahead of smells' naming.

On the other hand, smells' names influence olfactory perception. A first evidence come from the studies who observed that providing names modulate evaluation of smells, on pleasantness, intensity, or arousal dimensions (Herz et al., 2001; Herz, 2003, De Araujo et al., 2005; Djerdjevic, 2008, Manescu, 2014). Furthermore, Kaeppler and colleagues (2019) investigated the correlation between ratings of perceptual properties of smells when participants generated labels and when labels were provided to them. In the case of false identification, the authors observed that correlations were higher when the labels provided were identical to the ones generated by participants than when true labels of the actual odorants (but different from the labels generated by participants) were provided. The authors suggested that mental representation formed by participants shapes olfactory perception. In the same time, Olofsson & Gottfried (2015) provided evidence that object representation is built very early during odor processing. In addition, results from Stevenson and Mahmut (2013) suggest that, in the case of smells, access to semantic information is conditioned on the retrieval of smells' names. Therefore, the study of the evaluation of naturalness in the absence of odor names appears as an interesting avenue of research.

In summary, the **Study 2 and Study 3 shed light on the relation between smell identification and perception of naturalness of smells**. Moreover, **Study 4 found that naturalness meaning is shared between visual and olfactory modalities**, reinforcing the observation that smell representation content is important to assess their naturalness. However, our results are **limited to the observation of the existence of a relationship**, as we did not manipulate specifically identification of smells. In addition, as discussed above, the question of the directionality of the effect is an interesting perspective; is identification influencing naturalness judgments, or naturalness perception determining the smell's identification.

4. Inter-individual and cultural variability

Evidence pointed out that olfactory perception is especially prone to inter-individual variability (Mantel et al., 2021), as well as to cultural variability (Ferdenzi et al., 2013). In addition, variability in naturalness definition may also result in variability in the perception and categorization of natural entities (Siipi, 2008; 2013). Therefore, our fourth hypothesis was that: *the naturalness perception is subject to high interindividual variability (H4)*.

Inter-individual variability was indeed observed in our different studies. In Study 1, although a majority of participants showed a positive attitude toward natural products, we observed inter-individual variability in the attitude toward naturalness. In Study 2, the results of the free association question with natural and artificial odors provided evidence of diversity in the conception of the naturalness of odors. However, the most striking evidence came from Study 3, in which we observed very little consensus on the assessment of the naturalness of odors. For the same odorants, the assessment varied most of the time from one extreme to the other, revealing that participants perceived the naturalness of odors very differently.

One factor that could explain this variability is the attitude toward naturalness. However, the relevance of attitude in explaining interindividual variability in perceived naturalness is not clear from our results. In Study 3 (Chapter 4), we did not find a significant effect of attitude toward naturalness on naturalness judgments. In Study 4 (Chapter 5) a significant correlation was observed between attitude toward naturalness of personal care products and evaluation of pleasantness of stimuli. However, one limitation of these studies are the sample sizes, as the number of participants varied between 16 and 34. Therefore, further studies are needed, with a larger sample, to clarify the relationship between attitude toward naturalness and perceived naturalness of odors. Larger samples would also allow for comparison of the assessment of naturalness as a function of demographic factors. Demographic factors, such as gender and age, affect olfactory perception (Rouby et al., 2009) and attitudes toward naturalness (Romàn et al., 2017), these dimensions may thus explain some variability in the evaluation of the naturalness of odors.

In addition, cultural variability was also observed in our studies. This variability was apparent in the results of Study 2, as the expected attributes of natural products (intensity of natural product odors and colors as well as the colors associated with natural products) varied between the American and French panels. In addition, in Study 4, the comparison of evaluation of

olfactory and visual stimuli between the French and American participants revealed some differences, although these panels were limited (N=34 for French panel and N=33 for American panel). American participants perceived images of buildings as less natural than French participants, but they perceived candy and fruit smells as more natural than French participants. In addition, American participants perceived candy smells as more pleasant on average than French participants. These results therefore suggest that the assessment of naturalness is variable across cultures. Nevertheless, studies on a larger panel of participants would further consolidate these preliminary results.

To sum up, we observed **interindividual variability in the attitude toward naturalness, as well as in the perception of naturalness of smells** in the Study 1, Study 2 and Study 3. In addition, results of Study 2 and Study 4 **suggest that evaluation of naturalness is variable across cultures**. However, the **samples sizes of Study 3 and Study 4 were limited**. The questions of the **relationships between attitude toward naturalness, as well as demographics factors such as gender and age, with the evaluation of naturalness** might thus be some interesting **perspectives**.

5. Limitations and perspectives

General limitations of our work should be addressed. A first limitation already raised above concerns the issue of sample size. Larger samples with a balanced representation of males and females or age groups might allow investigating how perceptions of naturalness vary as a function of these factors. In addition, in the French population, participants were volunteers or relatively low-paid. Therefore, those who agreed to participate in the study were often people with a particular interest in olfaction, which may introduce a bias in our data. Finally, the cultural area studied targeted two distinct cultures, but nevertheless limited to participants from WEIRD countries, i.e. coming from western, educated, industrialized, rich and democratic countries.

Therefore, the extension of this research to new cultural areas could be particularly interesting. Indeed, the definition and perception of naturalness vary according to culture. Although the dichotomy between humans and nature has become mainstream in Western cultures, other cultures have very different representations of the place of humans in Nature. The anthropologist Philippe Descola (2005) has indeed observed that other cultures do not distinguish between humans and nature. For some cultures, humans and living entities do not

differ in their essence, only in their bodies, while for other cultures, all entities are different, and the human-nature distinction is not relevant to organize these differences (Descola, 2005). Moreover, the vocabulary available to describe odors also varies across cultures (Boisson, 1997). Cultures whose names refer to odors as percepts (e.g. Maniq language use abstract words to describe odors rather than source-based references, Wnuk & Majid, 2014) rather than to odors' sources may therefore show a different pattern of cognitive modulation by semantic odor names than the populations we studied.

Another general limitation is related to the debate on perceptual and decisional processes. Indeed, although we used the term of “perception of naturalness”, disentangling perceptual and decisional processes is not an easy task. As mentioned in the first chapter of this document, naturalness is a concept somewhat vague relying on the judgments and evaluations. Therefore, more than modulation of naturalness perception, the dimensions related to naturalness might influence naturalness evaluation rather than perception strictly speaking. However, our experimental work does not allow us to state unambiguously which of these two effects is the right one.

In our discussion, we also raised several limitations about the choice of odorants. Indeed, we have limited our research on the effect of the naturalness of the source to the question of odor production (natural vs synthetic), and further research may explore the question of the effect of chemical complexity on the perception of naturalness. In addition, our research has been mostly limited to pleasant odors, and to somewhat natural but not very natural odorants. Future studies could explore the perceived naturalness of unpleasant odors, as well as expanding the range of naturalness of the entities included in the experiments beyond raw food or natural consumers good. The inclusion of very natural entities, such as wild plants or animals, may also shed light on the question of attitudes toward wilderness. At the same time, wilder stimuli may be less familiar, expanding our understanding of the relationship between familiarity and naturalness.

Finally, a fruitful avenue is to further characterize the effect of dimensions identified as related to the evaluation of naturalness (pleasantness, intensity, identification) on naturalness evaluation. The intensity dimension would be particularly well suited to this type of study, as it is a dimension that is easily manipulated. For example, asking participants to evaluate naturalness of several odorants presented at different concentrations (3 or more) would clarify the effect of intensity on naturalness perception. Further investigating the effect of identification

on the perception of naturalness could also tell us something about the cognitive modulation of odor perception. Colors could be a good way to study this issue, as colors have been shown to modulate odor identification (Zampini et al., 2008; Zellner et al., 1991). In addition, studying the perception of naturalness could also be of interest in the absence of the odor name to determine if identification occurs ahead of evaluation of naturalness or not. Indeed, in Study 3, participants were not able to skip naturalness evaluation or to answer that they did not know, although they may be did not identified the smell. On the one hand, if name retrieval is a necessary condition for evaluating the naturalness of odors, participants unable to identify odors should not be able to evaluate them along the naturalness dimension. On the other hand, naturalness evaluation could come from smell recognition even in the absence of smell identification. A third interesting path concerns the evaluation of naturalness of very unfamiliar smells, as providing very unfamiliar smell would also preclude smell recognition. In summary, the investigation of the relation between naturalness evaluation, identification, recognition, and more generally mental representation of smells would be interesting to better understand naturalness perception as well as olfactory processing.

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Appendix

Appendix 1- On the contribution of the senses to food emotional experience

On the contribution of the senses to food emotional experience

Dantec M^{1,2,3§*}, Mantel M^{1§*}, Lafraire J², Rouby C¹, Bensafi M¹

¹ Lyon Neuroscience Research Center, CNRS-INSERM-University of Lyon, France

² Institute Paul Bocuse Research Center, Ecully, France

³ Marketing, Sensory & Consumer Research, V. Mane Fils, Grasse, France

* Co-first authors – equal contribution, in alphabetical order

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[§] Corresponding authors

Lyon Neuroscience Research Center

CNRS UMR5292 and INSERM U1028,

University Claude Bernard of Lyon

Centre Hospitalier Le Vinatier

Bât. 462 – Neurocampus Michel Jouvét

95, boulevard Pinel - 69675 Bron CEDEX

Email: morgane.dantec@institutpaulbocuse.com; marylou.mantel@ens-lyon.fr

Abstract

Emotions are an important component of our daily lives and contribute to behavior as well as general well-being. Foods are prominent sources of emotions (e.g. enjoyment, disgust...). One question that may arise in food research is how the different senses interact to create a unified affective representation of food. Indeed, current research suggests that rather than a unimodal processing of each sensory aspect of a food, there is a very early and almost undistinguishable integration of the senses, especially for the construction of flavor. In the present paper, we argue that a multisensory approach is necessary to understand the way senses converge to enable an emotional experience when perceiving food. We further put an emphasis on the fact that such multisensory integration is influenced by higher-order cognitive processes and possibly by emotions as well. After presenting theories in the field as well as experimental data, we discuss some paradigms that could pave the way for future research on food-induced emotional processing.

Keywords: Emotion – Food – Perception – Cognition - Multisensory integration - Cortex – Flavor

1. Introduction

In the last decades, research on affective sciences allowed for a better understanding of the neural underpinnings of emotions, that is the relationship between body and brain (Anderson & Phelps, 2001; Bechara et al., 2000; Berridge & Robinson, 2003; Critchley, 2003; Hamann & Canli, 2004; LeDoux et al., 1988; Morris et al., 1998; Phillips et al., 1997; Rolls, 2000). Affective sciences are rooted in the work of physiologists and philosophers at the turn of the 20th century, who considered emotions through both their biological and cognitive manifestations. William James (James, 1884) and Walter Cannon (Cannon, 1927) set out to discover whether the source of emotion was central (first triggered by cognition) or peripheral (first triggered by the body). Later, in the 1980s, cognitive theorists debated the existence of cognitive appraisal ahead of the elicitation of emotion. Zajonc (Zajonc, 1980) postulated that the affective and cognitive systems were relatively independent, in contrast to Lazarus (Lazarus, 1982) who postulated that the release of emotion required prior cognitive evaluation. Although the work of James and Cannon focused on the neural bases of emotion, in the mid-20th century, Papez (Papez, 1937) and McLean (MacLean, 1949) enlarged the description of these neural networks and put forward the idea of a cortical control of emotional response, allowing cognition, context and experience to modulate emotions.

The relationship between cognition, emotion and behavior is still debated among researchers in this field, with particular stress on both the sensory channels triggering emotions (visual, auditory, tactile, gustatory, olfactory, internal signals...) and the type of responses they evoke (subjective feelings, behavioral, autonomic or cortical responses). In that context, the case of food is of particular interest since it is a multi-sensory object that combines both distal (visual, auditory, orthonasal olfaction) and proximal (gustatory, retronasal olfaction, tactile) sensations. As an example, distal cues like the smell of croissants when approaching a bakery, or the vision of fresh croissants, initiate a positive emotion which will be reinforced by proximal sensations during ingestion: taste, touch, retronasal olfaction. Even the auditory feedback during actual consumption contributes to food enjoyment (Zampini & Spence, 2004). Moreover, the literature in the field has shown that food can evoke a large range of emotions from joy to guilt (Macht & Dettmer, 2006), with pleasant emotions being reported more frequently than unpleasant ones (Desmet & Schifferstein, 2008).

A prominent question raised by the community and still unresolved to this day is how the different senses contribute to these food-induced emotions. An intuitive answer to this question is that each sensory input individually contributes to emotion, in an additive way. However, in many situations, it seems far from being the case. For distal sensations, discordance may occur between the respective affective contributions of sensory modalities: a well-presented fish on my dish provides not only appetizing visual appearance, but simultaneous olfactory cues may trigger disgust if “this fish smells bad”. For proximal sensations, the same discordance can occur while one is eating a tasty salad: a single sand grain detected might lead to rejection. Therefore, in these conflicting cases, the resulting emotion is not easily predictable from individual sensory channels. In fact, multisensory integration matters: the literature in the field clearly demonstrates that it is the combination and integration of these senses that generates the global emotion associated to food and that it is difficult to perceptually tease apart their respective contributions. In practice, studying the contribution of each sense individually would be methodologically unsound because it is not representative of the multisensory machinery involved in normal food processing.

In the present paper we argue that multisensory experience contributes more to emotion than the sum of affective contributions of individual senses: the whole is more than the sum of its parts. This claim will be first supported by theories and experimental data showing that multisensory integration is needed to make sense of environmental information. Second, we will present a series of studies showing that multisensory integration is associated with a rich emotional experience, and that this experience is even stronger when the association between certain sensory features is congruent. Third we will present how this integration leads to a unified emotional experience when processing food and how cognition affects this process. We will conclude by sketching some promising research avenues for the scientist interested in food-related emotions and their sensory and cognitive underpinnings.

2. Multisensory integration is a way to make sense of complex information

Concordant with Gibson’s ecological theory (Gibson, 1979), the brain is wired to find relevant objects in its environment, such as food, for which the biological response is hedonic and linked to our survival (Prescott, 2012). Multisensory integration is a way to increase the detection and identification of relevant stimuli when a single sense would provide unclear or

incomplete information (Small & Prescott, 2005). For example, a subthreshold concentration of an odor is more easily detected if presented with a subthreshold concentration of a taste compound (Dalton et al., 2000). Stevenson (Stevenson, 2014) argues that, at the perceptual level, the brain is specialized to process objects especially for the chemical senses in which the stimulus range is very large. The individual chemical senses, i.e. taste, smell and trigeminal sensation, do not process objects by themselves but rather a part of a broader multisensory flavor object, in which they are perceived together. Thus, the perception of flavor is inherently configural, or holistic.

Theoretical models have shown that the growing complexity of the neural system leads to a small-world type of organization, i.e. there are both local processing of intramodal features of sensory stimuli and global integration to form unified percepts (Tononi & Sporns, 2003). According to the Distributed Domain Specific Hypothesis (Mahon & Caramazza, 2009), the information that is related to a common semantic domain such as food is processed through a network of brain regions that respond to any physical input related to this domain: thus, visual presentation of a food stimulus also activates other sensory components of the same food representation (Simmons et al., 2005). Neuropsychological studies have shown that the loss of one modality does not mean that the semantic knowledge of food is lost as well (Luzzi et al., 2007). Functionally, this allows robust representation of food through multiple channels.

In sum, multisensory integration is the answer of the brain to stimuli that are often very complex and that are thus processed as unified objects. Integration allows for a distributed representation of food, easily reactivable through the stimulation of one sensory modality and less sensitive to brain damage.

3. Multisensory processing is associated to a rich emotional experience

Although emotions related to food are usually investigated by unimodal sensory proxy (e.g. through food odor or images), some authors compared the emotional response between unimodal and bimodal or even multimodal experimental conditions. This emotional response is generally characterized in terms of subjective pleasantness of the stimuli or in the recruitment of emotional neural networks. In the rest of the paper we will use the term pleasantness to refer to the emotional valence judgements made by the subjects on unimodal or multimodal stimulations. At the perceptual level, de Araujo et al. (2003) asked human volunteers to rate the

pleasantness of two sensory stimuli, one gustatory (sucrose) and one olfactory (strawberry), either presented separately or simultaneously. They showed that the bimodal condition was consistently perceived as more pleasant compared to the sum of the two unimodal conditions. In the same vein, McCabe & Rolls (2007) showed that, while glutamate is not very pleasant when presented alone, it is perceived as more pleasant when combined with a vegetal odor compared to the sum of the conditions of glutamate alone and vegetal odor alone.

At the neural level, sensory inputs from different modalities are integrated in heteromodal areas, including the orbitofrontal and cingulate cortices, insula, hippocampus, prefrontal cortex and some parietal areas. These associative regions compute the individual significance of the stimulus from the sensory pathways' information, but also depending on the context, past experiences, as well as expectations and beliefs. This influence of such cognitive factors will be discussed in sections 6 and 7.

Several studies showed that the activation for a bimodal association is greater than for unimodal conditions. For example, in the study by McCabe & Rolls (2007) presented above, the researchers also demonstrated that the combination of glutamate and vegetal tastes induced a greater neural activity than each individual component. Furthermore, Gottfried & Dolan (2003) showed the additional involvement of the orbitofrontal cortex and the posterior cingulate cortex for an association of visual and olfactory stimuli. However, this was found only in a congruent condition (see section 4). Bensafi et al. (2013) reported this supra-additive activation of the orbitofrontal cortex in an olfactory and trigeminal combination, only in a congruent situation as well.

4. Congruency matters in multisensory processing of food and their emotions

The concept of congruency is essential to understand the interaction between the sensory modalities. It can be defined in the context of food research as “the extent to which two stimuli are appropriate for combination in a food product” (Schifferstein & Verlegh, 1996). At the behavioral level, the association between odors and semantically related images facilitates odor detection, both in reaction time and accuracy of detection (Gottfried & Dolan, 2003). Congruency also affects perception of intensity for odor-color associations (Zellner et al., 1991b). Many studies also showed an effect of congruency on emotional response. For example,

Zellner and her colleagues reported that colors modulated the perceived pleasantness of an odor, as grape odor is rated as more pleasant when colored in purple compared to yellow (Zellner et al., 1991b). De Araujo and colleagues also showed that strawberry odor is perceived as more pleasant when associated with sucrose compared to monosodium glutamate (de Araujo et al., 2003). This congruency effect was also retrieved for visual-auditory association, visual-tactile, or for olfactory-trigeminal (Bensafi et al., 2013) and olfactory-auditory association (Seo & Hummel, 2011; Velasco et al., 2014). Moreover, Schifferstein and colleagues showed a positive correlation between pleasantness of odor-taste mixtures and the degree of congruency of the associations (Schifferstein & Verlegh, 1996). Congruent associations were rated as more pleasant than incongruent ones, but also more pleasant than the sum of the unimodal stimuli (de Araujo et al., 2003; du Bose et al., 1980; Schifferstein & Verlegh, 1996).

Interestingly, heteromodal areas do not process incongruent and congruent food stimuli in the same way. Indeed, Small et al. (2004) showed that a congruent bimodal association (sweet taste and vanilla odor) induced additional activation in the anterior cingulate cortex, insula, posterior OFC, prefrontal and parietal cortices, and not an incongruent association. Likewise, de Araujo et al. (2003) showed that perceived congruence between stimuli (strawberry and monosodium glutamate or sucrose) was positively correlated with the activity in anteromedial orbitofrontal regions. Using a combination found in soda drink, the association between orange and carbon dioxide, (Bensafi et al., 2013) found a different activation pattern in the cingulate gyrus and hippocampus between congruent (CO₂ and orange) compared to incongruent (CO₂ and rose) condition. Additional activity in orbitofrontal cortex was also reported with congruent association between visual (images or color) and olfactory stimuli, whereas incongruent association did not induce such activation (Gottfried & Dolan, 2003; Österbauer et al., 2005).

In sum, experimental evidences from behavioral and neuroscience studies strongly suggest that the emotional experience is richer and recruits more emotional networks for a bimodal congruent association of sensory stimuli compared to unimodal presentation and/or incongruent associations.

5. A unified emotional experience in food processing

Usually, when confronted with a multisensory object such as food with congruent sensory inputs, individuals experience a unified emotion without differentiating the individual senses

that contributed to it. This is especially the case for the chemical senses. Indeed, from the first stages of life, there is a form of sensory fusion between taste and smell, which may be innate but that is also very early reinforced through the concomitant presentation of taste and retronasal smell when eating (Verhagen & Engelen, 2006). This fusion can happen at the peripheral level for senses that share a receptive structure (such as taste and temperature), as well as at the central level when the modalities are separated. At the neural level, there is an overlap between many regions involved in both smell and taste, such as the insula, the amygdala, the orbitofrontal cortex and the cingulate cortex (Veldhuizen et al., 2010). In fact, the sensory and emotional coding of food belongs to the reward system, a network involved both in anticipating and consuming food reward. This is true for olfaction, taste but also vision (Rumiati & Foroni, 2016a).

Through learning processes, these sensory elements bind together when they are simultaneously presented ending in a unified perception associated with an emotional experience. Flavor is an example of such fusion, as the default perception is holistic but, according to some authors, can still be separated into individual components if needed (Prescott, 2012). Most of the time, we are not conscious of this fusion, as even the sense of taste is usually merged with tactile perception and difficult to deconstruct.

This relationship between food's sensory attributes and emotional experience is however far from being static. Indeed, from one day to another, the same food will evoke different emotional responses, depending of the internal state or feeling of satiety. Even during meal consumption and digestion, induction of emotion by sensory characteristics of food is dynamic. Everybody has already experienced how cooking odors are appealing and pleasant before the meal when one is hungry, and how these same odors are unbearable and induce disgust when the belly is full. This phenomenon, based on the work of Cabanac (1971), is called alliesthesia: the state of repletion of a person influences the subjective pleasantness of foods' odors and taste. This modification of hedonic response 1) develops slowly after food consumption, 2) is relatively unspecific as all food's odors are affected, and 3) depends of nutrients content assimilation in the duodenum (noncaloric foods were found to have no effect on alliesthesia) (Rolls, 1986). However, decrease in pleasantness of smell, appearance, taste or texture occurs even during consumption of food and before digestion. This hedonic modulation is done through a process called sensory specific satiety (SSS) which appears during consumption of food, reducing pleasure of experiencing this food (see Hetherington & Rolls (1996) for a discussion on sensory

specific satiety). SSS is specific of types of food sharing the same sensory attributes and lasts at least 1 hour. For example, results from Guinard and Brun' study (1998) showed that, just after consumption of a sweet meal (either after 2 ou 20mn), pleasantness and desire to eat food decreased strongly for sweet food but not for salty food, while the opposite effect was observed after consumption of salty meal. They also observed SSS based on texture: consumption of soft food during meal decreased pleasantness and desire to eat another soft food (Guinard and Brun, 1998). Therefore, the link between emotion and sensory attributes of food is a dynamic phenomenon, as emotion induced by sensory dimensions of a palatable food fluctuates during and after consumption.

6. Cognitive contribution to the unified emotional food experience

The sections above highlight that food related emotions are not just determined by the sum of the respective affective contributions of the sensory modalities (smell, taste, vision, ...) but also by the interplay between these senses (e.g. cross-modal interactions and congruency effects). There is a relative consensus that cross-modal interactions and multisensory integration processes depend on cognitive representations. It means that certain associations between sensory features belonging to distinct senses are due to higher-order cognitive factors such as a shared semantic label. Related to our issue of interest, there are also emotionally mediated cross-modal correspondences, whereby two sensory features could be matched at a perceptual level because they share similar affective features (Roque et al., 2020; Spence, 2011b). Furthermore, the multisensory interactions responsible for the constitution of a unified object representation (e.g. a food representation) partly depend on belief or assumption, the so-called *unity assumption* (Chen & Spence, 2017; Welch & Warren, 1980 for a review). The latter seems also to be involved in the integration of the affective contributions of distinct sensory modalities (Chen & Spence, 2017).

Concepts and categories are also involved in the construction of food-related emotions. It is from these mental representations that derives the feeling of familiarity, defined as a prominent driver of food preference and enjoyment (Birch, 1979). Conversely, foods appearing as novel might induce intense emotions such as fear. This phenomenon is the so-called *food neophobia*, and it characterizes human beings (especially during development) and many animals (Crane et al., 2020; Lafraire et al., 2016).

Another abundant literature on the cognitive contributors to food perception and emotions concerns consumer's sensory and hedonic expectations (see Piqueras-Fiszman & Spence, 2015 for review). Sensory and hedonic expectations embed a variety of representations, that correspond to almost everything that might be thought about a given product prior to actual consumption. For instance, we may gain information about a product through distal sensory modalities (vision, orthonasal smell, exteroceptive touch), and we may form sensory or hedonic expectations about this product from these pieces of perceptual information (e.g. it will taste bitter or it will just taste bad). Even chemical senses such as taste might trigger expectations that can ruin meal experience. Indeed, it has been shown recently that the first bite sets a taste expectation that might modulate the taste of the remainder of a food (Dijksterhuis, Boucon, Le Berre, 2014). As emphasized by Piqueras-Fiszman and Spence (2015), most of the studies on sensory and hedonic expectations have focused on the consequences of the potential disparities between the expectations and the actual experience of consumers. In a nutshell, high discrepancies might trigger protective mechanisms and intense negative emotional reactions (Sakai, 2011; Yeomans, 2008). On the contrary, you might be aroused or even pleased by slight deviations from what you were initially expecting (Schifferstein, Kole, & Mojet, 1999), and satisfaction of expectations might lead to boredom.

The state of the art sketched above stresses the fact that the emotional dimension of food does not arise from a single sensory modality, but rather from the interplay between all the sensory features of a stimulus, cognitions and emotions. Furthermore, this well-documented interplay recently started to challenge the way the relationships between perception, cognition and emotion has been theorized so far.

7. Cognitive and emotional penetrability of perception

The previous paragraph puts an emphasis on the influence of cognitive factors on food perception and evaluation, like sensory and hedonic expectations grounded in information conveyed by the distal sensory modalities (Koza, Cilmi, Dolese, & Zellner, 2005 ; Zampini & Spence, 2004). However, as suggested by the literature on hedonic expectations, the relationships between our senses and non-sensory representations (cognitive and emotional) seems to be bidirectional, since emotions also might influence food perception. But does this

literature provide sufficient evidence to conclude that food perception might be penetrated by cognitions and emotions?

One may actually consider perception as an inferential process allowing loops between sensory processing and expectations (see (Clark, 2013 for a review). Indeed, recent neuroimaging evidence speaks in favor of cognitive loops applied to taste (Samuelsen et al. 2012; Gardner & Fontanini, 2014; Kusumoto-Yoshida, I., Liu, H., Chen, B. T., Fontanini, A., & Bonci, A., 2015) and to smell (Zelano et al., 2011; Howard, Gottfried, Tobler, & Kahnt, 2015). More interestingly given the scope of the present paper, it has been recently put forward that these expectations or predictions are not restricted to higher-order conceptually structured representations such as beliefs but include emotions as well. Emotional penetrability of perception is the idea that emotions influence the perceptual processes (understood *as distinct* from higher-order conceptual systems, like categorization, reasoning, etc.). This hypothesis received recently a great deal of attention in the field of visual perception. Individuals who report feelings of happiness visually perceive hill steeper than those reporting sadness (Brosch et al., 2013). In the food domain, experimental results provided evidence that affective state has an effect on food perception. Desira and colleagues (2020) for example, induced rather joviality or sadness by showing movies to human volunteers: participants from the joviality condition rated beer as tasting better and sweeter than those in the sad condition. In an ecological context, Noel and Dando (2015) studied the effect of the emotional state induced by sport competition on ice cream perception. Their results showed that participants perceived more intensely sweet taste and less intensely sour taste in positive affect condition than in negative affect condition. Authors hypothesized that sour ice cream was more liked in the positive affect condition because of this decrease of sourness perception. However, these studies might be suspected to suffer from methodological weaknesses, in the sense that there were not able to disentangle effects of emotion on perception from effects on post-perceptual processes (e.g. attention, memory or judgements). Indeed, they generally observed an influence of emotion on liking *judgment* or intensity *judgement* rather than a direct effect on perception (see Niedenthal & Wood, 2018 for a similar argument and a critical review in the non-food domain). Thus, if these experimental results speak in favor of emotion's influence on perception, further studies are needed to overcome this methodological locks.

8. *Conclusions and perspectives*

Many studies on the contribution of different senses to food-induced emotions relied on unimodal or bimodal experience of food. However, multisensory integration is a key part of food representation and food emotion. Thus, the relative weight of each sense contributing to food emotions needs to be examined from a multisensory and cognitive perspective. Moreover, the directionality of the relationships between food perception, cognition and emotion must not be presupposed. We conclude below with some theoretical and empirical considerations that may pave the way for future studies to reach a better understanding of the origins of food-related emotions.

Considering sensory loss studies. Since emotion processing in the food domain is rarely unimodal, investigating specific sensory loss could be a way to better understand the respective role of our senses. Indeed, the spread of anosmia and ageusia in the context of the COVID-19 ongoing pandemic is an unfortunate example of the importance of chemical senses in food emotion, since these specific sensory deficits seems to be related to severe diminution of pleasure in eating (Coppin, 2020).

Distinguishing between the stimulus and the object. Moreover, it is worth noting that food emotions have been extensively studied through pleasantness and disgust. However, work on food emotion suggests that food emotional experience is not limited to pleasantness (Macht & Dettmer, 2006). For example, Thomson et al. (2010) investigated how the sensory characteristics of a particular food (chocolate) are associated with different emotions. It is important to note that, here, food was considered as a whole object, and not as a single sensory dimension, meaning that Thomson et al. tested the impact of different tastes on chocolate-induced emotions, not the effect of taste upon odor perception. The extensive literature on cross-modal interaction offers interesting perspectives to understand food emotion, but it is important to be careful on the measured variable. Indeed, it must be the evoked emotion of food as a whole rather than of a single food sensory property (e.g. odor).

Considering eating and meal context. Beyond the difference between the stimulus and the object, it is also essential to consider the spatiotemporal context and the environmental conditions (noise, ambient smell... Kotler, 1974) characterizing meal contexts and surrounding the food. This will allow for a better understanding of emotion inducers (Meiselman et al.,

2000). Indeed, more ecological settings are needed for generating robust data (i.e. ecologically valid) on the drivers of food-induced emotions.

Accounting for individual differences. There is great inter-individual variability in food perception and preferences, driven by genetics, cultural background and personal history. Such diversity is observed both at the sensory and hedonic levels. Indeed, when considering the chemical senses, there is no common sensitivity to odors, tastes and trigeminal stimuli, which allows for a wide combination of individual differences in the perception of food depending on their individual senses' thresholds (Lundström et al., 2012). In addition, odors that are associated with sweet taste are not universal and depend on the way that pairing with sweetness happens in different cultures (Nguyen et al., 2002). There are also individual differences that can occur in certain health conditions, like obesity, in which the reward value of food is modified and, by extension, its pleasantness (Rolls, 2015).

Studying mental and non-food representations. A fifth essential notion that needs to be considered is the mental context (Chastain, 1975; Lafraire, 2017). This notion captures the idea that heterogeneous types of representation are deeply interrelated in human cognition (memory images, concepts, and visual, gustatory, olfactory, bodily, affective... representations, etc.). Following this idea, non-food representations (e.g. bodily representations) are sometimes critical for the understanding of affective responses to food stimuli. Indeed, recent studies on fragile populations such as anorexic patients or subjects with a very low BMI (Pergola et al., 2017; Urdapilleta et al., 2005) have suggested that they tend to perceive and categorize foods differently from healthy subjects. According to these seminal studies, these patient sample and classify food depending on their functional properties and especially on their expected effects on the body. One may thus assume that for these patients, food representations and eating activities are so tightly connected to bodily representations (Gadsby, 2017) that the sensory properties of the food are completely trumped by these functional bodily-related properties which in turn become an important driver of affective responses to food. We suggest that this relationship between food and non-food representations should be more investigated in the future. More generally, psychological entities themselves such as emotion, cognition and perception will probably have to be considered not as distinct discrete mental entities but as deeply integrated processes (Pessoa, 2008).

In sum, researchers in food processing might consider several ways to better understand the emotional value of food for the individuals: using paradigms centered on sensory loss or enhancement, improving the ecological value of their protocols, reconsidering the variables to measure and accounting for the environment, interindividual variability in sensory processing and mental context. With this in mind, further studies may be more suited to uncover the mechanisms underlying emotional processing of food and the relative importance of each of the senses.

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