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On the role of statistical learning at the very beginning of learning to read

Teng Guo

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UNIVERSITÉ
DE LORRAINE

SLTC Doctoral School
ATILF UMR 7118 (CNRS-UL)

On the Role of Statistical Learning at the Very Beginning of Learning to Read

A dissertation submitted to the
UNIVERSITÉ DE LORRAINE

by Teng GUO

in partial fulfilment of the requirements for the degree of
DOCTEUR EN PSYCHOLOGIE DE L'UNIVERSITÉ DE LORRAINE

December 18, 2023

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SHORT ABSTRACT (ENGLISH)

Based on a cognitive approach to the inner structure of writing systems and the existing literature on explicit instruction, statistical learning, and the *syllabic bridge* theory, we proposed a theoretical framework in which a level of associative units mediates between orthographic and phonological representations. The research presented in this thesis had two overarching aims: first, to examine whether statistical learning, at this level, allows prereaders to extract grapheme-phoneme correspondence (GPC) regularities in letters-to-syllable associative learning, and second, to determine whether phonological representation is influenced by statistical orthographic knowledge generated by associative units. To address the first aim, the research in Experiments 4.1 and 4.2 demonstrates that prereaders' exposure to a greater variety of GPC regularities embedded in letters-to-syllable associations enhances their phonemic awareness and the generalisation of non-taught syllables. These findings suggest that the potential involvement of SL in learning letter-to-syllable associations might facilitate the acquisition of the alphabetic principle at the very beginning of learning to read. Addressing the second aim, the research in Experiments 5.1 and 5.2 showed that individuals' responses to a phonological task are influenced by statistical orthographic knowledge, resulting from the interplay between orthography and phonology through associative units. These findings offer insights into early reading acquisition methods, underscoring the importance of tailored explicit instruction and SL in literacy development.

RÉSUMÉ COURT (FRANÇAIS)

Basé sur une approche cognitive de la structure interne des systèmes d'écriture et sur la littérature existante sur l'enseignement explicite, l'apprentissage statistique (AS) et la théorie du pont syllabique, nous avons proposé un cadre théorique dans lequel un niveau d'unités associatives sert d'intermédiaire entre les représentations orthographiques et phonologiques.

La recherche présentée dans cette thèse avait deux objectifs principaux : premièrement, examiner si l'apprentissage statistique, à ce niveau, permet aux pré-lecteurs d'extraire des régularités de correspondance graphème-phonème (CGP) dans l'apprentissage associatif lettre-syllabe, et deuxièmement, déterminer si la représentation phonologique est influencée par les connaissances orthographiques statistiques générées par les unités associatives.

Pour répondre au premier objectif, les expériences 4.1 et 4.2 montrent que l'exposition des pré-lecteurs à une plus grande variété de régularités GPC intégrées dans les associations lettre-syllabe améliore leur conscience phonémique et la généralisation des syllabes non enseignées. Ces résultats confirment le rôle important de l'AS dans l'apprentissage des associations lettre-syllabe et dans l'acquisition du principe alphabétique aux tout débuts de l'apprentissage de la lecture.

Répondant au deuxième objectif, les recherches menées dans les expériences 5.1 et 5.2 ont montré que les réponses des individus à une tâche phonologique sont influencées par des connaissances orthographiques statistiques, résultant de l'interaction entre orthographe et phonologie au travers d'un système cognitif d'unités associatives.

Ces résultats éclairent les mécanismes d'acquisition précoce de la lecture, soulignant l'importance d'un enseignement explicite personnalisé et de l'AS dans le développement de la littéracie.

LONG ABSTRACT

The inner structure of the alphabetic writing system is conceived as a system of correspondences between letters and phonemes (Gelb, 1952; DeFrancis, 1989). It is generally recommended to teach grapheme-phoneme correspondences (GPC), known as the *phonics* approach (Castles et al., 2018; Rayner et al., 2001). This thesis addresses a dimension of learning often overlooked: the role of statistical learning (SL) performed by the brain after memorising written-speech pairs. The thesis argues that SL restructures the associated pairs at the level of a set of associative units.

Chapter 1 presents a cognitive perspective on the inner structure of writing systems. The grapheme's function is to convey phonological or semantic information, which, when combined with others, guides the reader towards articulation units such as signs or syllables. It is from this perspective that a new modelling of reading acquisition has been developed.

Chapter 2 analyses the explicit instructions given at the beginning of learning and highlights that these instructions comprise two aspects: explaining the alphabetic principle and memorising orthographic-phonological pairs. This latter aspect, often neglected, constitutes an associative environment. From this environment, processes for detecting and extracting GPC regularities would be automatically triggered (e.g., Apfelbaum et al., 2013). The end of the chapter provides a review of literature on the relationship between reading learning and statistical learning.

Chapter 3 proposes a theoretical framework for the very beginnings of reading learning (Guo et al., 2023). The *syllabic bridge* hypothesis is that pre-readers start learning to read by associating letter strings with pronounceable phonological units (Doignon-Camus & Zagar, 2014). Vazeux et al. (2020) demonstrated that an approach based on the *syllabic bridge* improves phonemic awareness more effectively than a phoneme-based approach. This result suggests that an SL mechanism would reorganise the ortho-phonological environment acquired

through the memorisation of learned syllables and would constitute a network of associative units between orthographic and phonological representations.

Chapter 4 reports two studies in prereaders that test the hypothesis of automatic triggering of SL. The results showed that the number of regularities that could be extracted from an ortho-phonological environment directly influences phonemic awareness performances (Experiment 4.1) and the reading of non-taught syllables (Experiment 4.2). These results confirm the major role of SL in acquiring the alphabetic principle at the very beginnings of reading learning.

An important prediction of Guo et al.'s (2023) theoretical approach and the reorganisation of the ortho-phonological environment memorised by SL is the formation of a cognitive system of associative units. Chapter 5 presents a longitudinal observation of the influence of this associative system on the perception of ambiguous syllables.

Chapter 6 presents the main conclusions of this thesis and the pedagogical perspectives it offers.

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RÉSUMÉ LONG

La structure interne de l'écriture alphabétique est conçue comme un système de correspondances entre lettres et phonèmes (Gelb, 1952 ; DeFrancis, 1989). Dans cette perspective, il est généralement préconisé d'enseigner ces correspondances, c'est ce qu'on appelle « l'approche phonique » (Castles et al., 2018 ; Rayner et al., 2001). Cette thèse aborde une dimension de l'apprentissage souvent négligée : le rôle de l'apprentissage statistique effectué par le cerveau après mémorisation de paires écrit/parole. La thèse défend l'hypothèse que l'apprentissage statistique restructure les paires associées au niveau d'un ensemble d'unités associatives.

Le Chapitre 1 présente une perspective cognitive de la structure interne des systèmes d'écriture. La structure interne des systèmes d'écriture détermine la manière dont les enfants apprennent à lire. Depuis la publication de l'ouvrage fondateur de Gelb, « Pour une théorie de l'écriture », en 1952, les grammatologues s'intéressent à la structure interne des écritures. Celle-ci est définie par la relation entre des éléments de l'écriture et des unités linguistiques, par opposition à la forme extérieure qui concerne les caractéristiques graphiques de l'écriture (Coulmas, 1999). Ce chapitre propose d'abord un bref historique de l'invention des premières écritures pleines » à travers le monde. Une majorité de grammatologues ont utilisé l'approche linguistique pour analyser la structure interne des premières écritures « pleines », en mettant l'accent sur les relations entre les symboles graphiques et les unités linguistiques. Toutefois, il n'existe aucun consensus parmi les grammatologues concernant la classification des systèmes d'écriture basée sur cette approche. Le chapitre introduit ensuite les nouvelles questions qui ont émergé durant l'invention des premières écritures. Enfin, on propose une approche cognitive pour définir la structure interne des systèmes d'écriture, argumentant que la structure interne ne concerne pas seulement les relations directes entre les symboles graphiques et les unités linguistiques. Plus important encore, le graphème aurait pour fonction de véhiculer des informations phonologiques ou sémantiques qui, combinées à d'autres, guideraient le lecteur vers des unités d'articulation : signes ou syllabes. C'est dans cette perspective qu'une nouvelle modélisation de l'acquisition de la lecture a été élaborée.

Le Chapitre 2 offre un aperçu succinct de la littérature existante concernant les instructions explicites en début d'apprentissage et l'apprentissage statistique dans le cadre de l'acquisition de la lecture. Dans les méthodes phoniques, on souligne souvent l'importance de l'aspect explicatif des instructions, c'est-à-dire de la prise de conscience que les lettres représentent des sons de parole qu'il s'agit ensuite de « fusionner ». Cependant, il y a aussi un aspect mnémonique qui consiste en la mémorisation des paires orthographique-phonologique.

Ce dernier aspect, souvent négligé, constitue un environnement associatif à partir duquel un mécanisme cognitif de détection et d'extraction des régularités est automatiquement déclenché. Ce mécanisme cognitif est connu sous le nom d'apprentissage statistique, et a été abondamment étudié dans le cadre de l'acquisition de la lecture depuis deux décennies. Nous en présentons d'abord une définition, puis nous passons en revue les tâches utilisées pour mesurer cette capacité : apprentissage de grammaire artificielle, temps de réaction sériel, et apprentissage de probabilités transitionnelles. Nous explorons ensuite la corrélation potentielle entre la capacité d'apprentissage statistique, mesurée par les tâches mentionnées ci-dessus, et la compétence en lecture. Une partie des études ont montré une corrélation positive entre niveau de lecture et capacité d'apprentissage statistique (e.g., Arciuli et Simpson, 2012 ; Frost et al., 2013), tandis que d'autres études n'ont pas observé de corrélation (e.g., Schmalz et al., 2019). En supposant qu'une telle relation existe, on a cherché les sources causales de l'impact de l'apprentissage statistique lors de l'apprentissage de la lecture. Les études ont montré plusieurs causes potentielles : la sensibilité des lecteurs aux régularités orthographiques, l'attribution de l'accent sur les mots, le traitement morphologique et syntaxique, et, le plus important, l'extraction des régularités de correspondances graphème-phonème. Nous faisons l'hypothèse que la mémorisation des paires orthographique-phonologique peut activer l'apprentissage statistique, qui permettrait aux pré-lecteurs de détecter et extraire régularités de correspondances graphème-phonème (e.g., Apfelbaum et al., 2013).

Le Chapitre 3 propose un cadre théorique des tout-débuts de l'apprentissage de la lecture (Guo et al., 2023). L'hypothèse du « pont syllabique » est que les pré-lecteurs commencent à apprendre à lire en associant des chaînes de lettres à des unités phonologiques prononçables (Doignon-Camus & Zagar, 2014). Vazeux et collègues (2020) ont montré qu'une approche basée sur le « pont syllabique » améliore davantage la conscience phonémique qu'une approche basée sur l'apprentissage des correspondances graphème-phonème. Ce résultat suggère qu'un

mécanisme d'apprentissage statistique réorganiserait l'environnement ortho-phonologique acquis par la mémorisation des syllabes apprises et constituerait un réseau d'unités associatives entre les représentations orthographiques et phonologiques. On développe un cadre théorique qui prend en compte ce processus aux tous-débuts de l'apprentissage de la lecture. Une caractéristique importante dans ce cadre théorique est la présence d'un niveau d'unités associatives, qui sert à réorganiser l'environnement ortho-phonologique via l'apprentissage statistique. Ainsi, nous posons deux questions de recherche pour mieux comprendre ce niveau d'unités associatives.

Le chapitre 4 présente deux expériences visant à examiner comment des enfants francophones pourraient mieux généraliser les régularités de correspondances graphème-phonème grâce à l'exposition à différents micro environnements orthographiques, constitués d'associations entre des suites de lettres et des syllabes. Ces expériences ont été menées séparément avec des enfants issus d'écoles maternelles standards ($n = 159$) et ceux provenant de réseaux d'éducation prioritaire ($n = 33$). La procédure était identique pour les deux expériences. Les enfants ont appris des associations lettres-syllabes au cours de séances d'apprentissage d'environ 100 minutes. Un ensemble d'associations permettait l'extraction de jusqu'à huit régularités de correspondance graphème-phonème, constituant ainsi un « micro-environnement orthographique riche », tandis que l'autre ensemble ne permettait d'extraire que quatre régularités, formant un « micro-environnement orthographique pauvre ». Des prétests et des post-tests ont été administrés pour évaluer le développement de la connaissance des lettres, la lecture de syllabes et la conscience phonémique dans chaque condition. Dans l'expérience 4.1, les résultats les plus significatifs ont été observés chez un sous-groupe d'enfants ayant une bonne connaissance des lettres mais une faible conscience phonémique au prétest ($n = 67$). Les résultats ont indiqué que les enfants formés avec le « micro-environnement orthographique riche » ont montré une plus grande progression en conscience phonémique que ceux formés

avec le « micro-environnement orthographique pauvre ». Dans l'expérience 4.2, les enfants formés avec le « micro-environnement orthographique riche » ont mieux généralisé avec des syllabes qui n'avaient pas été explicitement enseignées durant les sessions de formation, par rapport au groupe du « micro-environnement orthographique pauvre ». Ces résultats confirment le rôle majeur de l'apprentissage statistique dans l'acquisition du principe alphabétique aux tout-débuts de l'apprentissage de la lecture.

Le chapitre 5 présente deux expériences visant à explorer la nature de la relation entre l'orthographe et la phonologie pendant l'acquisition de la lecture. Nous avons utilisé une tâche de conscience phonologique avec des stimuli ambigus pour observer si les réponses à cette tâche sont influencées par l'interaction entre l'orthographe et la phonologie médiée par des unités associatives. Dans l'expérience 5.1, cent quarante-quatre enfants de la première à la cinquième année et 61 étudiants francophones de premier cycle universitaire ont complété une tâche de comptage de syllabes pour 80 pseudomots monosyllabiques acoustiques de type consonne-voyelle-consonne et consonne-consonne-voyelle-consonne. Le nombre de syllabes dans les pseudomots était ambigu (une ou deux) selon des critères acoustiques (Ensemble A), étant donné que les rimes finales peuvent être prononcées et perçues avec ou sans un schwa vocalique /ə/ (par exemple, [flud] ou [flu.də]), et selon des critères orthographiques (Ensemble B) puisque certaines de leurs rimes finales peuvent fréquemment s'écrire avec un « e » (par exemple, [-uj]) tandis que d'autres s'écrivent fréquemment sans un « e » (par exemple, [-us]). L'analyse des résultats a montré que (1) les pseudo-mots étaient plus fréquemment comptés comme des séquences d'une syllabe lorsqu'ils avaient une forte probabilité de ne pas s'écrire avec un « e » plutôt que lorsqu'ils avaient une faible probabilité de ne pas s'écrire avec un « e » et (2) cet effet augmentait avec le niveau de lecture, confirmant l'influence de la représentation mentale orthographique et de l'acquisition de la littéracie sur les tâches phonologiques. Dans l'expérience 5.2, nos résultats ont montré que les pré-lecteurs comptaient

sans ambiguïté les pseudo-mots comme des séquences d'une syllabe, confirmant que l'ambiguïté des stimuli ne dépendait pas des critères acoustiques, mais principalement des critères orthographiques et de l'acquisition de la littéracie. En conclusion, nos résultats offrent une nouvelle perspective sur la relation entre la phonologie et l'orthographe, suggérant une connexion non pas directe mais plutôt une connexion entre les représentations mentales phonologiques et orthographiques médiée par des unités associatives.

Dans le chapitre 6, nous offrons un résumé de nos principales contributions, complété par une discussion sur les implications théoriques de nos résultats. Nous réfléchissons ensuite aux limites de l'étude et proposerons des orientations futures pour la recherche.

CHAPTER 1: INNER STRUCTURE OF WRITING SYSTEMS

*The inner structure of writing systems determines how children learn to read. Since the publication of Gelb's seminal book, *A Study of Writing* (1952), grammatologists have been studying the inner structure of writing systems, focusing on the relationships between graphic symbols and linguistic units. This chapter provides a brief overview of the invention of the first full writings from around the world. From a cognitive perspective, we argue that if a universality among writing systems exists, it may be found not only in the relationships between writing and sound, but also in the combination of clues or of information that guide readers towards the units of articulation. This fresh interpretation of the inner structure of writing systems sets the stage for the main issue addressed in this thesis.*

PLAN OF CHAPTER 1

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The work of Ignace J. Gelb (Gelb, 1952, first edition; Gelb, 1963, second edition), *A Study of Writing*, marked a major turning point in the study of writing systems and their functioning. Gelb laid the foundations for a new discipline: grammatology. This discipline approaches the study of writing not from the perspective of its outer form, but from its relationship with spoken language, which he referred to as the inner structure.

Coulmas (1999) defined the inner structure of writing systems as the “*structural constitution of writing systems in their relation to language, as opposed to the outer form which has to do with graphic characteristics*” (p. 234). Coulmas illustrated this definition with two examples. In one example, he noted that Egyptian and Babylonian writings differ significantly in outer form but share a *logosyllabic* inner structure. In another example, he pointed out that, while both Spanish and English use the Roman alphabet and therefore share the same outer form, they differ substantially in inner structure due to their distinct grapheme-phoneme correspondences : Spanish operates predominantly on a phonemic level, while English operates on the morphophonemic and often lexical levels.

A linguistic approach to writing systems

For Gelb (1963), the study of the inner structure of writing systems was based on the idea that full writing is a system of *phonetic signs* that express linguistic elements. He distinguished two types of *phonetic signs*: *phonetic semantic signs*, which denote words, and *phonetic non-semantic signs*, which denote syllables and phonemes.

In what follows, we will examine three important aspects in Gelb’s conception of the inner structure of writing systems: first, the transition from the forerunners of writing to full writing; second, the *principle of phonetization*, and third, the idea of the development of writing systems that led to the classification of writing systems.

Forerunners of writing

Initially, Gelb (1963) distinguished full writing (in contrast to partial writing, see DeFrancis, 1989) from its forerunners, which represented the earliest attempts to express thoughts through visual symbols. In simple terms, a full writing system is one that enables the representation of all thoughts that can be articulated through speech. The earliest evidence of what might be considered writing is hard to distinguish from images. Gelb introduced the term *semasiography* to describe a stage where drawn forms, akin to gestural communication, could convey meaning directly without involving linguistic structures. Based on Native American productions, Gelb identified two types of processes: the *descriptive-representational* device, where scenes were depicted using several drawings organised in a more or less systematic way, and the *identifying-mnemonic* device, which involved representing an object, a person, or a place through a particular drawing.

The process that led to full writing was *identifying-mnemonic*, that is, the representation of words. This represented the first step towards a visual system that mimics speech: when drawings or symbols were systematically associated with an object or a character, reading becomes possible. Gelb (1963) highlighted this decisive advancement and emphasised an important property of writing: the spatial order of the symbols follows the temporal order of speech units. Upon realising that words could be signified through markers and symbolic traces, a superior method for human intercommunication was conceived. This breakthrough, which requires a strict order of signs aligned with speech, stands in contrast to the *descriptive-representational* device.

At this stage in the evolution of writing, it theoretically became possible to write down all the statements of a language. The necessary condition would have been to generalise the principle of association and to create a written symbol for every morpheme in the language; this potential writing system was known as *logography*. However, such a system was practically

unfeasible due to the mnemonic limitations of the cognitive system. This system would have involve tens of thousands of distinct symbols, not including the additional symbols needed to represent proper nouns and words borrowed from foreign languages. Furthermore, the continuous evolution of language, with new words emerging and old ones disappearing, presented another challenge. As Gelb (1963) notes, no such writing system has ever existed. A significant point in Gelb's view is that merely representing the meanings of words does not suffice to achieve full writing.

Principle of phonetization

To break free from the constraints of *logography*, representing the sounds of a language becomes imperative. The principle at the heart of the inner structure of writing systems is what Gelb (1963) terms the *principle of phonetization* or the *rebus principle*. This principle involves representing words that are difficult to depict graphically (e.g., abstract concepts) with signs that denote words that are similar in sound and easy to draw. Gelb exemplifies this with a Sumerian case where the sign of an arrow, pronounced /ti/¹, is used to write the word "life,"² which is also pronounced /ti/. This is how Gelb's (1963) defined the *principle of phonetization*:

"Principle of Phonetization. A principle, called in modern usage the Rebus Principle, by which word signs which are difficult to draw are written by signs expressing words which are similar in sound and easy to draw. Thus, in Sumerian, the word ti, 'life', is expressed by the picture of an arrow, which also is ti in Sumerian" (p. 252).

This process emerged around 5000 years ago in the Sumerian civilisation during the Uruk III period. It can be observed in all the earliest writings, including Chinese and Maya.

¹ Pronunciations are enclosed in back slashes or square brackets.

² Meanings of words, characters, or morphemes are enclosed in double quotation marks.

Aligning with Gelb (1963), all grammatologists concur that the cornerstone of the invention of full writing lies in employing *phonetization*. This means that in languages such as Sumerian, Chinese, and Mayan, the focus transitioned from representing the word—a unit that carries meaning—to depicting the sound of the word, particularly the syllable sound.

According to Gelb (1963), *phonetization* represents a pivotal step in the history of writing, emerging as the most significant development in its evolution. This process, which involves representing the linguistic elements of spoken language, marks a departure from early attempts that focused on conveying meanings. This innovative approach facilitates the representation of any linguistic form using symbols with conventional syllabic values, thereby laying the foundation for the emergence of full writing systems.

Evolution and classification of world's writing systems

For Gelb (1963; 1974), all writings originated from the invention of *phonetization* (see Figures 1.1 and 1.2). The Sumerians, Chinese, and Egyptians came up with the idea of representing syllables by written elements. However, owing to conservatism, their writing had not fully developed, and they retained many elements representing words. The cuneiform writing of the Akkadians (Cooper, 1996), as well as Japanese and western Semitic writings, became syllabic, with an increasing number of written elements representing syllables (without meaning); however, most of these writings still contained logograms. Only the western Semitic writings (e.g., Aramaic and Phoenician) completely rid themselves of Egyptian logograms: the elements of writing were letters that denoted syllables with undetermined vowels (see Gelb, 1974; however, this hypothesis has been rejected by most grammatologists). Finally, the Greeks systematised the writing of vowels and, in doing so, achieved complete denotation of speech segments: the alphabet was invented.

The inner structure of writing is thus consistent across all scripts: elements of writing represent syllables and phonemes. For Gelb (1963; 1974), the nature of the inner structure of writing stood for a direct association between elements of writing and phonological units. The classification of writing systems is defined by the linguistic grain, which is denoted by the elements of writing.

Gelb’s work initiated a new approach to the study of writing systems, and, for the most part, the grammatologists who succeeded him adopted Gelb’s main hypotheses. However, these working hypotheses have not led to an agreement on the classification of the various writing systems of the world (see Appendix A for a summary of the classification of writing systems).

The main disagreements stem from the challenges involved in determining the nature of the linguistic unit corresponding to a grapheme. For instance, how does one determine whether the Chinese character 像 represents a morpheme or a syllable? Or whether Phoenician graphemes denote syllables (Gelb, 1952), syllables without vowel indication (Gelb, 1974), or consonants (Daniels, 2017)? It must be acknowledged that the theoretical perspective of a direct correspondence between graphemes and linguistic units of different grains does not allow for the definition of the inner structure of a writing system.

Figure 1.1

Classification of writing systems by Gelb (1963)

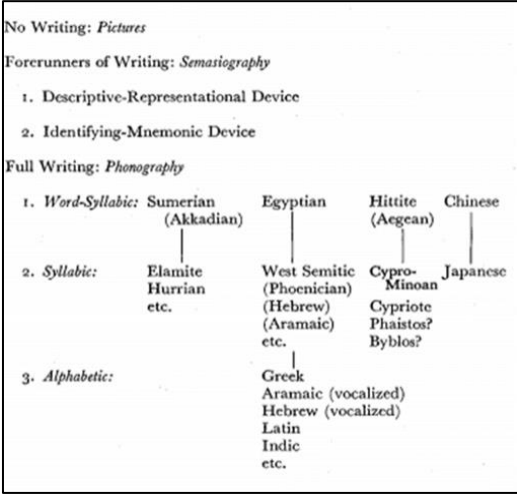


Figure 1.2

Classification of writing systems by Gelb (1974)

| THE TYPOLOGY OF WRITING | | | | | | |
|--|--|---------------|-------------|--|--------------------------|--|
| NO WRITING: Pictures | | | | | | |
| FORERUNNERS OF WRITING: Semasiography | | | | | | |
| 1. Descriptive-Representational Devices | | | | | | |
| 2. Identifying-Mnemonic Devices | | | | | | |
| FULL WRITING: Phonography | | | | | | |
| 1. <i>Logo-Syllabic</i> | | | | | | |
| Sumerian + Akkadian + Hittite cuneiform | Egyptian | Proto-Elamite | Proto-Indic | Cretan | Hittite hieroglyphics | Chinese + Chinese derived systems |
| 2. <i>Syllabic</i> | | | | | | |
| Type A (with vowel indication) | Type B (without vowel indication) | | | Type A (with vowel indication) | | Type A (with vowel indication) |
| Cuneiform Syllabaries: | West Semitic Syllabaries: | | | Aegean Syllabaries: | | Japanese Syllabary |
| Elamite Hurrian Uartian Hattic, Luwian, Palaic, etc. | Proto- Sinaitic Proto- Palestinian Phoenician Hebrew Aramaic etc. | | | Linear A Linear B Phaistos disk Proto-Byblian Cypro-Minoan Cypriote | | |
| <i>Mixed Syllabic B + A</i> | | | | | | |
| | Ugaritic Persian Cuneiform | | | | | |
| <i>Mixed Syllabic A + Alphabetic</i> | | | | | | |
| | Iberian | | | | | |
| 3. <i>Alphabetic</i> | | | | | | |
| | Greek Aramaic (vocalized) Hebrew (vocalized) Latin Indic Korean etc. | | | | | |

The alternative to Gelb's theoretical propositions came from DeFrancis (1989). DeFrancis challenged Gelb's categorisation of writing systems, particularly regarding the establishment of *word-syllabic* writing as a distinct category parallel to *syllabic* and *alphabetic* systems. Even though Gelb identified three distinct systems, all of which inherently combined

morphemic and phonetic elements (see Figure 1.2), DeFrancis questioned the rationale behind distinguishing *word-syllabic* from *syllabic*. He argued that Chinese and other supposedly *word-syllabic* scripts should not be viewed as distinct types. Instead, DeFrancis suggested they were a subcategory of syllabic systems, which he labeled *morphosyllabic*, setting them apart from the *pure syllabic* category, which included scripts like Japanese and Yi (p. 253).

For DeFrancis (1989), all full writings were phonographic, even the earliest full writings. He referred to Martinet's concept of *double articulation* (Martinet, 1960/1964). According to Martinet, the productivity of language resided in this *double articulation*. The first level of articulation involved monemes (a term that corresponded to Saussure's *sign*), which enabled the formation of all the utterances in a language with a few thousand elements. The second level of articulation pertained to phonemes, which, with a few dozen elementary sounds, facilitated the production of all morphemes. DeFrancis believed that this rule, as articulated by Martinet for spoken language, also applies to writing.

In discussing the classification of writing systems, DeFrancis (1989) critiqued both Gelb (1963, 1974) and Sampson (1985), among other scholars, for neglecting a critical issue that Martinet highlighted concerning the vital need to divide spoken morphemic units into smaller phonemic ones. He echoed Martinet's argument, positing that a logographic or morphemic writing system was inconceivable unless it subdivides the expansive array of logographic or morphemic units into a more manageable number of phonetic ones. DeFrancis noted that Chinese and other *morphosyllabic* systems achieved this essential economy by employing a reduced number of syllabic units (p. 254).

DeFrancis' (1989) classification fundamentally relied on the argument that to be productive, writing, like language, must possess two levels of articulation: the morpheme and a phonetic level, which involves the syllable and the phoneme. In Chinese, the phonetic level was represented by the syllable, depicted by the grapheme, which is the phonetic component of

Chinese compound characters. The semantic elements served no other purpose than to clarify ambiguous phonological information.

DeFrancis (1989) adopted the classification principles of most grammatologists and also proposed an arboreal classification (see Figure 1.3), which distinguished mixed writing systems from “pure” systems on one hand, and on the other, identified the nature of the phonological information, whether it be syllable, consonant, or phoneme.

Later, DeFrancis, in collaboration with Unger, would advance the idea that no writing system was purely *phonographic* or purely *logographic*, but that they could be classified along a continuum situated between these two poles (DeFrancis & Unger, 1994; see Figure 1.4).

Sproat (2000; see Figure 1.5) and later Rogers (2005, see Figure 1.6) adopted this idea, proposing that writing systems could be classified according to two criteria: the amount of *logography* and the type of *phonography*.

Figure 1.4

Non-arboreal classification of writing systems by DeFrancis and Unger (1994)

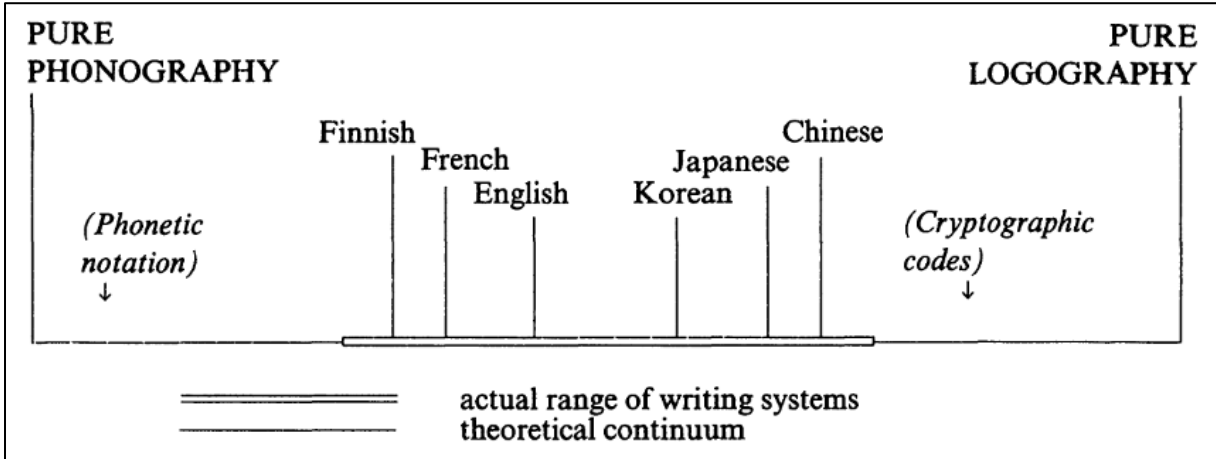


Figure 1.3

Classification of writing systems by DeFrancis (1989)

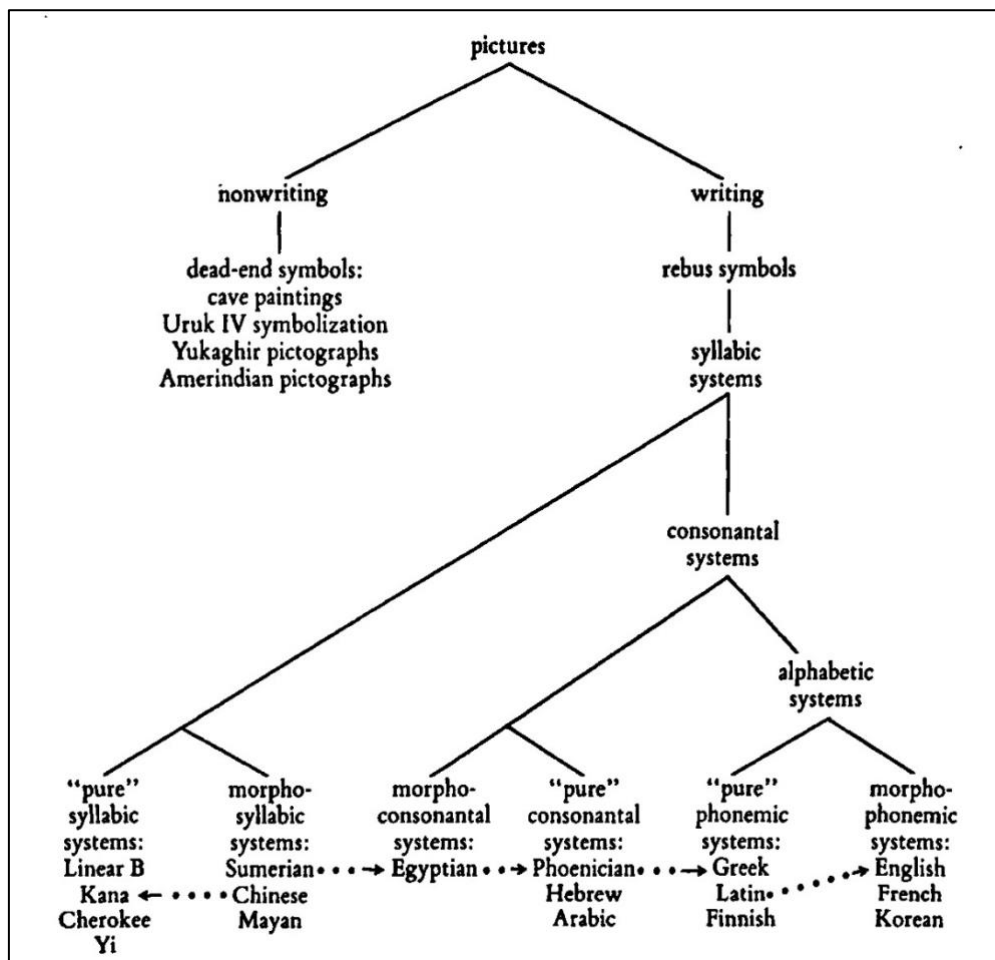


Figure 1.5

Non-arboreal classification of writing systems by Sproat (2000)

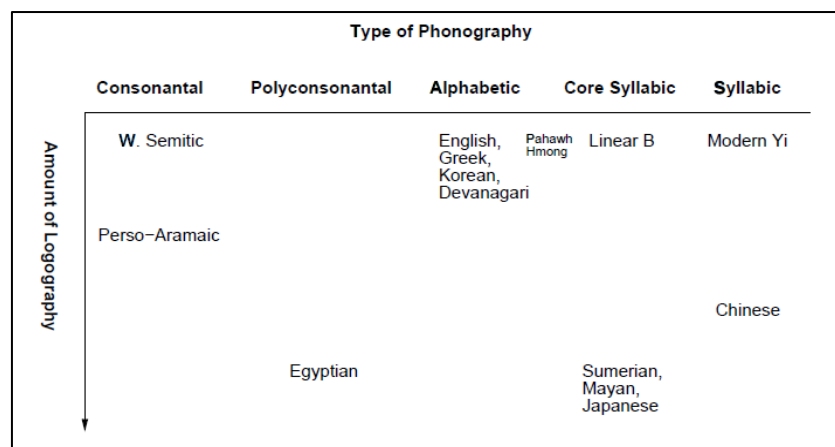
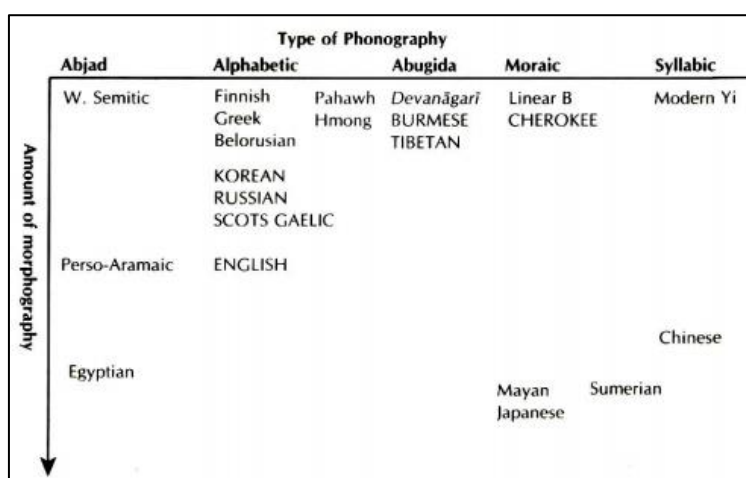


Figure 1.6

Non-arboreal classification of writing systems by Rogers (2005)



The main interest of DeFrancis’s (1989) approach lay in the hypothesis that, to represent speech, writing must achieve the same level of productivity as language. The hypothesis, which suggested that this level of productivity was defined by Martinet’s (1960/1964) principle of *double articulation*, was likely an intriguing path to explore. However, it seemed that DeFrancis’s reasoning encountered an issue when he asserted that this level is attained simply when the grapheme represented a phonetic unit. The first objection involved the status of what he considered “additional information”: he specified neither its exact nature nor the relationship this information maintains with the *double articulation* system. The subsequent models by Sproat (2000) and Rogers (2005) illustrated the difficulty of defining the two dimensions: there was no consensus on the units of the phonographic axis, and the logographic axis was defined by a “quantity” without clarity regarding how this quantity could be evaluated.

As we have seen, the lack of agreement on the typology of writings reflected an incomplete description of the inner structure of scripts. This was probably one of the reasons why Daniels’ (1996; 2017) descriptive typology had been successful.

Daniels presented a typology for classifying scripts used over the past five millennia or so, introducing six types of writing systems. These were firstly, the *morphosyllabary* (or *logosyllabary*), where each character represented a morpheme and could be used for its sound as well as its meaning; secondly, the *syllabary*, in which each symbol represented a syllable; thirdly, the *abjad*, which was a Semitic-type script where each character represented a consonant; fourthly, the *alphabet*, as seen in Greek-type scripts, where each character represented either a consonant or a vowel; fifthly, the *abugida*, resembling Sanskrit-type scripts, where each symbol represented a consonant accompanied by a specific vowel, usually /a/, with other vowels (or no vowel) indicated by consistent additions to the consonant symbols; and lastly, the *featural* script, such as the Korean type, where characters' shapes correlated with the phonetic features of the segments they designated (p. 43).

The merit of Daniels' (1996; 2017) work was evident in its provision of a detailed, and presumably exhaustive, description of the world's writing systems. However, Daniels largely disregarded the interplay between writing and language, even asserting that writing was not structured in the same manner as language. He went so far as to deem the concept of a grapheme nonessential, arguing that, despite efforts by American structuralists to treat writing as a subsystem of language, writing systems did not function like linguistic systems and lacked an "emic" level, rendering the widespread term "grapheme" misleading (pp. 65-66).

Daniels' a-theoretical stance could likely be attributed to the lack of a coherent perspective when analysing the relationships between writing and speech. However, we believe that it is possible and crucial to define a theoretical framework for the evolution of writing systems.

Novel questions

The goal of grammatologists was to find a system for classifying the world's writing systems based on their inner structure, that is, by determining the size of the linguistic grain that corresponded best to the units of each writing system. Parallel to these reflections and attempts, several researchers had been interested in the conditions that allowed the invention of writing. We will address three questions that, in our view, clarify the inner structure of the earliest writings: first, the progressive development of a logographic system; second, the necessary conditions for the invention of phonetization; and third, resolving the resulting homography issue.

Logographic system (Schmandt-Besserat, 1996; Coulmas, 1989)

We have seen that Gelb (1963) differentiated between *phonographies* and *semasiographies*. Within *semasiographies*, he identified a *identifying-mnemonic device* during which the elements of writing represent a specific person or object.

The process that led to full writing was *identifying-mnemonic*, that is, the representation of words. This represented the first step towards a visual system that mimicked speech: when drawings or symbols are systematically associated with an object or a character, reading became possible. Gelb highlighted this decisive advancement and emphasised an important property of writing: the spatial order of the symbols followed the temporal order of speech units.

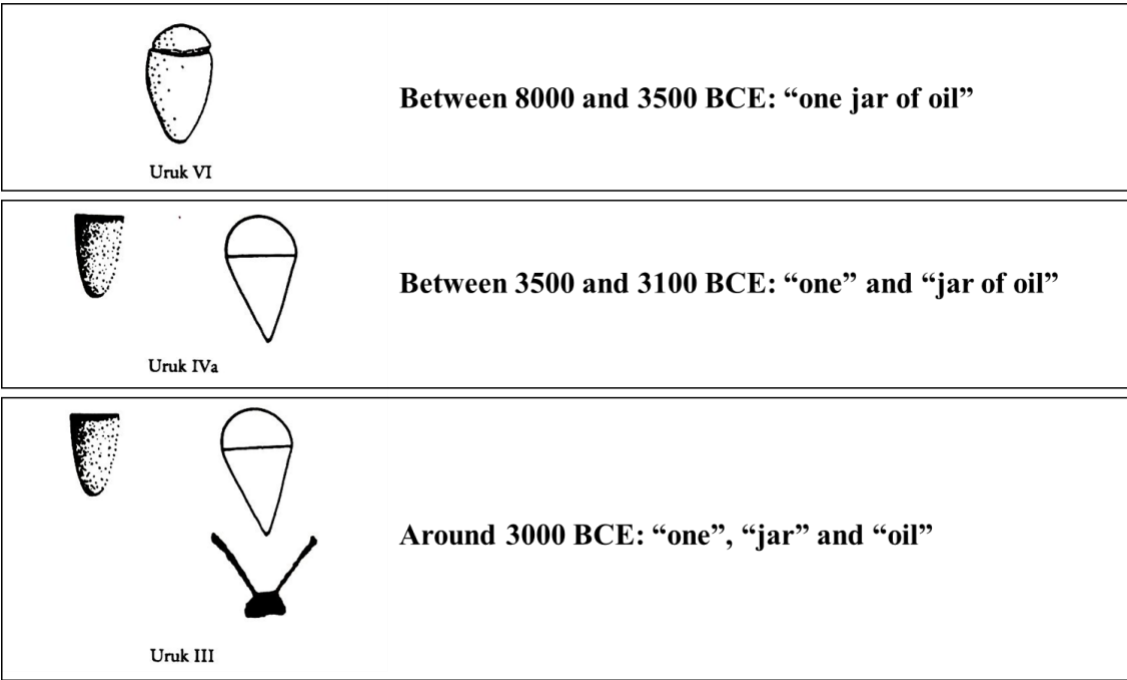
Such a system of correspondences between written words and spoken language may have seemed intuitive to us today. However, the research of Schmandt-Besserat (1996) illustrated that this development did not occur overnight. While there were occasional instances of representing an object in the world with a symbol, the systematic use of a one-to-one correspondence between written words and spoken language was the result of a long maturation process. Schmandt-Besserat worked on artifacts³ found in Mesopotamia dating from 9000 to

³ Small objects made by stone or clay.

2000 BCE. These small elements, varying in shape, were used to count or record goods, likely involved in transactions. The relationship between these objects and what they referred to was direct: a particular item (token) corresponded to a commodity (e.g., an ovoid shape represented a jar of oil, a cross within a circle indicated a sheep, etc.). These objects were placed in clay containers. Then, these containers were sealed (in bubbles), presumably to prevent theft during transactions. Naturally, this caused another problem: the contents of the clay bubble were obscured (one would have had to break it to reveal its contents). The solution was to imprint the shapes of the objects on the exterior of the bubble before sealing them inside. According to Schmandt-Besserat, these imprints constitute the origins of logographic writing.

Figure 1.7

Evolution of Sumerian tokens, adapted from Schmandt-Besserat (1996)



What was interesting was to observe the evolution of these representations (see Figure 1.7). Between 8000 and 3500 BCE (Uruk VI era), each type of commodity was represented by

a specific tally mark. For example, jars of oil were counted with ovoid forms, with numbers indicated analogically: one token represented both the good and its quantity, e.g., one jar of oil. To represent “three jars of oil,” the same token (the ovoid) was imprinted three times. Subsequently, between 3500 and 3100 BCE (Uruk IVa era), symbols denoting quantity and goods were represented by two distinct symbols: the ovoid symbolised “the jar of oil,” while the quantity was represented by another sign (for example, the number 1 was represented by a cone). It was only later on, in the Uruk III era around 3000 BCE, that the three morphemes of the phrase “a jar of oil” came to be represented by three distinct symbols: one symbol represented the number “one,” a second “jar,” and a third “oil”. Schmandt-Besserat perceives a relationship between the emergence of writing and the ability to use abstract cardinal numbers (1, 2, 3...) for counting objects. Schmandt-Besserat summarised that the development of counting can be divided into three pivotal stages: 1) one-to-one correspondence, 2) concrete counting, and 3) abstract counting. She hypothesised that the invention of writing could be the outcome of abstract counting.

While the hypothesis is intriguing, it is noteworthy that the evolution of the writing of the term “a jar of oil” represented the gradual emergence of systematic correspondence between a written symbol and a spoken morpheme. This process might seem obvious to a literate person nowadays; however, it provides evidence of the slow evolution of adapting the structure of writing to the abstract structure of speech, ensuring the productivity of writing. For example, with two symbols for the cardinal numbers {1,3}, two symbols for containers {jar, bowl}, and two symbols for liquids {oil, wine}, one can express $2 \times 2 \times 2 = 8$ descriptions of merchandise.

Coulmas (1989) attached particular importance to these tokens and hypothesised that they constituted part of the missing link between *pictographic (semasiographic)* writing and full writing. To him, these tokens are *signs* in the Saussurean sense of the term because they visualise the basic relation between a sound image and an idea. Although it was often said that

phonetization represented the decisive stage in the invention of full writing. This stage is preceded by a crucial process for the emergence of full writing: the systematic and unambiguous association of a visual symbol with a word (or morpheme), which was *logography*.

How phonetization was invented? The missing link (Coulmas, 1989)

How was *phonetization* invented? Gelb did not explain it. For Coulmas (1989), the first symbols, which represented words, could also be seen as Saussurean *signs*. Through this remarkable operation, words were materialised, acquiring a status of concrete objects that were both visible and tangible. Gnanadesikan (2009) used the metaphor, likening words written on a page to butterflies pinned to a board. The existence of concrete objects facilitated the materialisation of speech units. Precisely, concrete objects representing spoken morphemes could be examined, analysed, and dissected.

Although all words (or morphemes) were *signs* containing a *signifier* and a *signified*, a nuanced difference existed, enabling us to hypothesise about the cognitive mechanics that led to the use of the first logographic symbols to denote syllables. Consider the Chinese symbol 象, which means “elephant” and is pronounced /xiang4⁴. Pronouncing this word engages both its sound and meaning, which are so closely associated in our cognitive system that they are difficult to disentangle. Saussure (1916/1959) described this interdependency: “*Language can also be compared with a sheet of paper: thought is the front and the sound the back; one cannot cut the front without cutting the back at the same time; likewise in language, one can neither divide sound from thought nor thought from sound; the division could be accomplished only abstractedly, and the result would be either pure psychology or pure phonology*” (p. 113).

⁴ Pronunciations of Chinese characters are enclosed in back slashes. The number represents tones, for example, /ma1/, /ma2/, /ma3/, and /ma4/ for the first through fourth tones, respectively.

For Coulmas (1989), during the *purely logographic* period, there was a gradual transition in how graphical representations were used. Initially depicting concrete objects (e.g., “ox”, “grain”, “fish”, etc.), these representations began to be associated solely with the sound of the words. Coulmas noted a pivotal point in this transition where the relation between the graphical signs and their phonic forms stabilised and became more prominent. This shift in dynamics made it conceivable to use these graphical signs exclusively for representing sound configurations, largely ignoring their original meanings. He discussed this in the context of understanding the cognitive processes that eventually enabled the distinguishing of what Saussure characterised as inseparable components of linguistic *signs*: the *signified* and the *signifier*. Coulmas emphasised that the abstraction process mentioned by Saussure was not merely theoretical but had been practically implemented by ancient civilisations such as, the Sumerians and the Chinese. By utilising logographic writing to represent hundreds of morphemes, these civilisations achieved this abstraction thousands of years ago, a phenomenon that far predated the publication of Saussure’s *Course in General Linguistics* in 1916.

Once the distinction between the signifier and the signified was established, it became possible to use graphical symbols to denote not signs, but speech sounds, specifically syllables. Coulmas (1989) explained this progression, stating, “*Gradually, the meaning side of the linguistic sign as a denotatum of the written sign was cancelled out. Thus phonetization progressed one step further. The primary value of the written sign had become a sound.*” (p. 32).

Coulmas’ (1989) conclusion was heavily influenced by Gelb’s (1952) assumption, namely, that the invention of writing resided entirely in *phonetization*. However, Coulmas’ analysis provided a very convincing explanation of how humanity conceived the idea of representing speech sounds. The visual representation of words likely had a major impact on the awareness of the dual nature of the spoken word, which simultaneously represented an object in the world and functioned as an auditory object. Furthermore, rather than saying that

logograms represented words (or morphemes), it might be more accurate to hypothesise that logograms denoted *signs* in the Saussurean sense of the term; that is, they encompassed both a *signifier* and a *signified*.

Nevertheless, we do not align completely with Coulmas' (1989) conclusion, which implied that the primary value of a written sign had transitioned into being a *sign* in the Saussurean sense of the term. We think that a more accurate assertion would be that the logogram can, depending on the circumstance, represent a *signifier*, a *signified*, or both at once. We hypothesise that once a word becomes written, it transforms into a concrete and permanent object. Consequently, it can become an object of manipulations—manipulations that have brought about an awareness of the dual facet of the Saussurean *sign*. After achieving this awareness, it became plausible to dissociate the two aspects of the *sign*: the *signifier* and the *signified*. In the subsequent sections, we will explore how this knowledge was leveraged to develop full writing.

Problem of homography (Boltz, 1986; 2000)

The widespread use of the *principle of phonetization* meant that a limited number of characters could, in theory, represent all the syllable sounds of a language, which could number in several hundreds. However, the *homophony* of the language could mechanically induce a high rate of *homography*. This homography presented a significant obstacle to the development of a full writing system. Contrary to Gelb's claim, the use of the *phonetization* was not the only process necessary for the invention of full writing.

Boltz (1986; 2000) developed a concept of the early stages of writing development, offering a slight divergence from Gelb's (1963) perspective. He outlined three stages: firstly, the *pictographic stage*, secondly, the *multivalent stage*, and finally, the *determinative stage*, which marked the arrival of full writing.

Like Gelb (1963), Boltz (1986; 2000) explained that in the *pictographic stage*, pictures were used to represent concrete, drawable objects, and each picture represented a whole word. However, this system had its limitations as it could only depict things that could be visually represented.

These drawbacks of a *purely pictographic* system were recognised by the early creators of Chinese script. They found two alternative ways to use pictographs, marking the beginning of the *multivalent stage*. This stage was characterised by a single graphic symbol carrying more than one meaning, either phonetically or semantically, but not both at once. Boltz outlined two key derivative processes employed at this stage. The first was the *paranomastic* process, more commonly known as the *principle of phonetization*, which utilised existing pictographs to represent words that were homophonous or nearly so. For instance, the Chinese pictograph representing “elephant” was also used to represent the words “image” and “appearance” due to their phonetic resemblance. The second process was the *parasemantic* process, involving the use of pictographs to represent words that, while not phonetically similar, shared a semantic connection. For instance, the Chinese pictograph representing “mouth” was used to denote “name” or “call”.

Boltz (1986; 2000) emphasised that these derivative processes marked the *multivalent stage*, highlighting a breakthrough realisation that a single graphic symbol could have more than one single semantic or phonetic value. The first stages were very similar to those described by Gelb, with the exception that new written words were derived not only from the pronunciation (or the *signifier*) but also from the meaning (or the *signified*). However, the significant difference between Gelb’s conception and that of Boltz pertained to the description of the third stage: the *determinative stage*.

For Boltz (1986; 2000), the multivalent use of graphs, enabled writing to represent a greater number of morphemes with a limited set of symbols. However, this expansion also

introduced a problem: ambiguity in the denotation of symbols. Boltz noted that the evolutionary path of the Chinese script, similarly to the trajectories observed in Mesopotamian cuneiform and Egyptian hieroglyphs, reached a point where the extensive *paranomastic* and *polyphonic* utilisation of graphs became more ambiguous than could be reasonably accommodated. This required clearly indicating the specific meaning or pronunciation intended in a given graphic, among several possibilities.

Thus, it was not merely the invention of *phonetization* that facilitated the development of a full writing system. A third method eventually emerged, involving the addition of determinatives to ambiguous graphs.

During this *determinative stage*, which marked the third pivotal phase in the evolution of the Chinese script, a secondary or supplementary graph was added to the main graph to specify or determine the intended meaning from various possibilities. This addition was necessitated by two forms of ambiguity that arose in the second stage: one due to the *paranomastic* use of graphs, leading to semantic multivalence (e.g., the symbol 口 denoting “mouth”, “name”, and “call”), and another arising from the polyphonic use of graphs, resulting in phonetic multivalence (e.g., “elephant”, “image”, and “appearance” all pronounced /xiang4/). Therefore, to address the two types of ambiguity present, two categories of determinatives were created: semantic and phonetic.

To resolve ambiguity in the meanings of certain graphs, secondary elements, known as *semantic determinatives*, were introduced. Consider the graph 求/qiu2/ which could originally mean both “pelt” and “seek”. To distinguish between these meanings, a supplementary graph symbolising 衣, which means “covering, clothing”, was added. This clarified that the intended meaning was 裘, meaning “pelt”, while leaving it unmodified signified “seek”. Another example is the graph 象/xiang4/, which can represent both “image” and “elephant”. To denote

“image”, an additional graph derived from the symbol for 人, meaning “man”, was incorporated.

If the intention was to convey “elephant”, the graph remained unchanged.

In a similar vein, *phonetic determinatives* have been used to clarify phonetic ambiguities. For instance, the graph 口 was polyphonically used for both /kou3/ “mouth” and /ming2/ “call, name”. To resolve the ambiguity, the graph 夕 /ming2/ “brighten” was added to the 口 to specify the pronunciation /ming2/ 名.

In the early stages of using *determinatives*, particularly *semantic determinatives*, their application was somewhat unpredictable and inconsistent; a determinative might occasionally appear or be absent in a character. Taking the modern representation of the term 象 “image” as an example, it can still occasionally be seen without the *determinative*. As time progressed, a norm was established, stipulating that when a *determinative* was added to a graph, it would henceforth be considered a fundamental component of that graph. This evolution in usage led to a standardisation in script wherein most characters comprised a central graph accompanied by at least one *determinative*.

Thus, the final barrier—which is the ambiguity arising from homography—has been overcome: each compound character is unequivocally linked to a morpheme. Moreover, a restricted set of symbols can denote the entire lexicon. Furthermore, the mechanism of determinatives, with its potential for recursive use, facilitates the inscription of new and foreign-origin words, thereby satisfying the necessary conditions for the script to be deemed fully evolved. Boltz identified a clear evolution through three foundational phases in the Shang dynasty inscriptions, emphasising that, by the final stage, the script had transformed into a robust, mature, and adaptable system, proficient in conveying the comprehensive spectrum of the language with efficiency and reduced ambiguity.

Duality principle (DeFrancis, 1989)

DeFrancis (1989) drew on Boltz's (1986) work to propose a new understanding of the inner structure of early writing systems, with a particular focus on Chinese. From the invention of *phonetization*, Chinese compound characters appeared; DeFrancis adopted Boltz's hypothesis that these characters should not be viewed as script units denoting morphemes, but as combinations adhering to a specific principle. Broadly speaking, he asserted that, all writing systems conveyed meaning via two mechanisms: firstly, through symbols representing sounds, acting as "*surrogates of speech*," and secondly, through symbols providing non-phonetic information. These two mechanisms, combined in varying proportions in different scripts, collectively embodying what he termed the "*duality principle*," forming the foundation of all genuine writing systems (p. 49).

According to DeFrancis, Chinese characters could construct a frame, referred to as SP, composed of a *semantic determinative* (S) and a *phonetic determinative* (P). A character might stand alone as a word, or it may combine with other non-phonetic elements to create more complex characters. For example, the character 马, pronounced /ma3/, independently represented "horse". When used as a phonetic determinative, it could be combined with a semantic determinative like 女, meaning "female", to formulate a compound character 妈, meaning "mother", pronounced /ma1/.

Thus, the vast majority of Chinese characters adhered to the SP structure. For DeFrancis, the pivotal part of a Chinese character was the phonetic component, which he regarded as the grapheme, while the semantic part provided "additional" information, necessitated by the ambiguity of the phonetic component. Contrary to what most grammatologists propose, he argued that all writing systems were phonetic. He also noted that Chinese was not the only writing system in which phonetic information was ambiguous; this was the case, for example, with English, which distinguished homophones by utilising different spellings (e.g., see vs. sea).

As we have seen, DeFrancis and Unger (1994) proposed a classification of scripts on a continuum (see Figure 1.4), positioning them between a phonetic pole and a semantic pole. No writing system existed that was purely phonetic (such as the International Phonetic Alphabet) or purely semantic; all the world's writing systems lay somewhere between these two poles.

The significant contribution of the *duality principle* lay in the multi-functionality of the elements of writing: firstly, to denote phonological units (such as the syllable, the phoneme, and the consonant, what he called “grapheme”), and secondly, to provide “additional” information that guided the reader towards the intended word. We will explore the possibility of extending this reasoning further, observing that in all writing systems, the elements of writing do not directly denote linguistic units but are primarily utilised to convey information. The *duality principle* of DeFrancis (1989) thus challenged the hypothesis that the sole function of the grapheme would be to denote linguistic units. The grapheme could also have the role of conveying information.

The oversight of DeFrancis (1989), as well as other grammatologists, was their excessive focus on *phonetization*, neglecting what seemed evident: the earliest writings employed both phonological information from the *signifier* and the information implied by the *signified*. This combination allowed for the creation of a writing system capable of documenting all spoken words. The productivity of Chinese was not rooted in the use of the second level of articulation. Instead, it was related to the amalgamation of cues from the first level of articulation, or the Saussurian *sign* (which, as Martinet specified, corresponded to the *moneme*). The second level of articulation, to be discussed later, was only harnessed by successors of these early writings. Essentially, all the primary writings used only the first level of articulation. This fact, going beyond Daniels' observation that the languages of these initial writings were monosyllabic, characterised the nature of these early scripts.

A cognitive approach to writing systems

Inner structure of first full writings

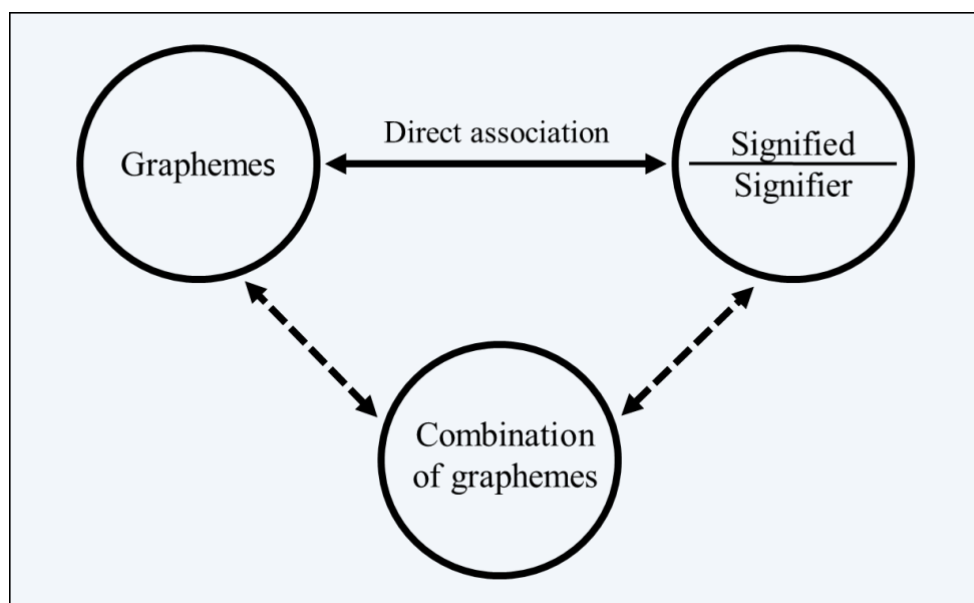
Here, building on the works of Boltz (1986), Coulmas (1989), and Defrancis (1989), we propose a cognitive approach to the invention of first writings. Initially, elements of writing were used as mnemonic aids for spoken words. The first spontaneous process was to associate spoken words with written symbols. This process gradually took hold until it yielded a set of symbols that, by convention, were systematically associated with a limited set of spoken words. The establishment of a systematic logographic writing system was the origin of the development of writing. As early as this period, the idea to combine existing symbols to create new ones came to light with the emergence of a need to represent new words. For instance, the word “to eat” in Old Sumerian was created by combining the symbols for “face” and “food;” in Chinese, the symbol for “bright” was constructed by associating the characters for “moon” and “sun”. Thus, new symbols were crafted from existing ones: writing evolved through a kind of tinkering. Thus, we observe the emergence of a second process for representing words: the combination of clues or information. Direct association and combination of clues are the two cognitive mechanisms used in writing to recover the sounds of words.

As Coulmas (1989) noted, the systematisation of the association between written and spoken words led to the materialisation of the dual nature of the internal representation of a word: both its meaning and its spoken sound, which Saussure conceptualised under the term “*sign*.” It is, of course, seemingly impossible to know how literate individuals of that era conceptualised this duality. However, the invention of full writing bore witness to the cognitive ability to manipulate the *signifier* and *signified* independently. *Phonetization* attested that the written symbol was used to represent not the syllable, but the signifier alone. Additionally, the mechanism described by Boltz (1989) demonstrated the ability to combine signifier and signified.

The description of the inner structure of first full writings should therefore rely on a cognitive approach, as illustrated in Figure 1.8. The elements of writing, which we call graphemes, directly denote a *sign* in Saussurean terms, that is, both the *signified* and the *signifier*. For example, the character 象 simultaneously denotes the *signified* “elephant” and the *signifier* /xiang4/. Gradually, this mechanism of direct association gave way to another mechanism: the combination of clues, which provides information for both the *signified* and *signifier* of the new compound character. And the grapheme will be used not to denote a linguistic unit, but to convey information (either semantic or phonological). For instance, the combination of the graphemes 象 and 人 provides a *signifier* clue and a *signified* clue for the new compound character 像, respectively. The new compound character itself respects the sign property that has two inseparable aspects: its *signifier* /xiang/ and its *signified* “image”. With the development of writing, this second mechanism has become the rule and is used for all newly written words. In Modern Chinese, less than 5% of words are represented by a single grapheme.

Figure 1.8

Cognitive representation of the inner structure of first full writings



Adaptation of writing systems

In this part, we will consider the evolution of writing not as progress, but as a diffusion and adaptation of this technology across various languages of the world. We therefore hypothesise that the same cognitive principles employed in the first writings (particularly the combination of graphemes) will be adapted to new languages.

Over the past 5000 years, writing has evolved. However, the term “evolution” is imprecise, and it is probably necessary to clarify what is meant by this term. For instance, Chinese writing, since the Shang dynasty, has evolved: the written vocabulary has encompassed the entire spoken vocabulary, and new words have been created by combining characters. There has been a recursive use of these combinations, such that compound characters have served as phonological or semantic indices, leading to the creation of hyper-complex characters comprised of three or four characters. While some characters have become obsolete, the pronunciations linked to certain characters have shifted, and their meanings have evolved. These changes have led to a greater complexity in the system of associative relations. Despite these developments, the core structure of the Chinese writing system has remained consistent. The reason is straightforward: for approximately 3500 years, it has adeptly achieved its primary goal of productivity (achieved through the combination of indices), allowing writing to effectively represent speech.

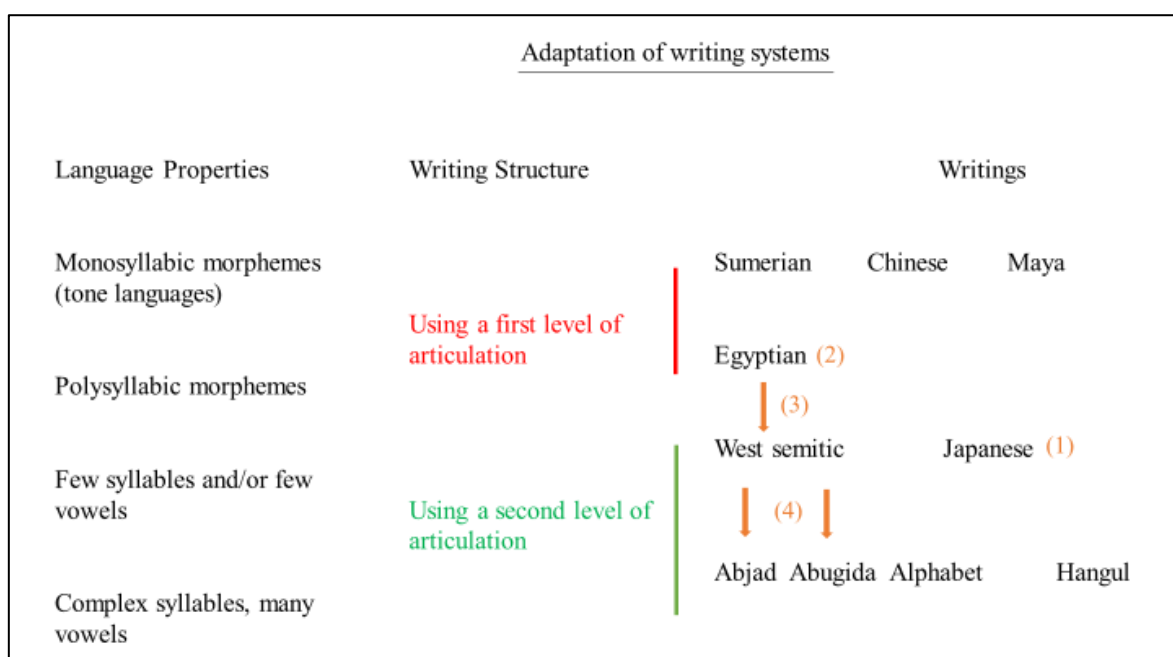
When discussing evolution of writing systems, the discourse often transitions from primary writing to *syllabic* writing and then to *alphabetic* writing (or even to *abjads* and *abugidas*). In this context, it is advisable to avoid the term “evolution,” as it might misleadingly suggest a sense of progress. The transition from the initial forms of writing to syllabic and subsequent forms tends to reflect adaptation rather than improvement. This adaptation arose due to a pronounced difference between the languages of those who invented writing and those who did not. Peoples such as the Japanese, Hurrian, or Egyptians, who did not initially have

writing, possessed languages featuring polysyllabic morphemes. Consequently, for these groups, utilising the combination technique of the *signifier* and *signified* was untenable. Such a method requires significant homophony, either covering all the syllabic sounds of a language or, at the very least, approximating them. Notably, languages with monosyllabic morphemes, like Chinese, are tonal languages. This is possibly true for Sumerian and Mayan as well. As a result, the phonological component of a character does not strictly represent a syllabic sound but instead serves as an indicator for a range of syllabic sounds. In the case of Chinese, this includes the four syllables corresponding to the four potential tones. As writing evolved, this approximation expanded to encompass rhyme and onset. Lastly, it is pivotal to highlight that the development of writing systems in polysyllabic languages consistently occurred through interactions with full writing systems: as observed with Japanese in contact with Chinese, Akkadian with Sumerian, and presumably Egyptian hieroglyphics with Sumerian.

In examining the invention of the first writing systems, we can identify four distinct types of adaptation (see Figure 1.9): (1) there was a shift from writing to polysyllabic languages through the creation of syllabaries. This was often paired with the preservation of logographic characters and employed the second level of articulation unit, the syllable; (2) we observe the unique instance of Egyptian—a polysyllabic language—where the writing system maintained the inner structure characteristic of the earliest scripts; (3) there was a transition from this Egyptian writing to Western Semitic scripts, which similarly employed the second syllabic articulation level as mentioned earlier; (4) the progression continued from Western Semitic scripts to languages that feature complex syllables, notably Indian and European languages.

Figure 1.9

Illustration of adaptation of writing systems



(1) Creation of syllabaries in polysyllabic languages

The first writings adapted to polysyllabic languages, and this adaptation substantially changed the very structure of writing by necessitating the representation of syllabic units within words. This adaptation process was both lengthy and gradual. For instance, the Japanese initially adopted Chinese writing, but during the early phases, they read and wrote exclusively in Chinese. It was only over time that they began to represent Japanese syllables using simplified forms of Chinese characters with similar sounds. As a result, writing incorporated a second level of articulation: that of the syllable. This transition profoundly altered the inner structure of writing.

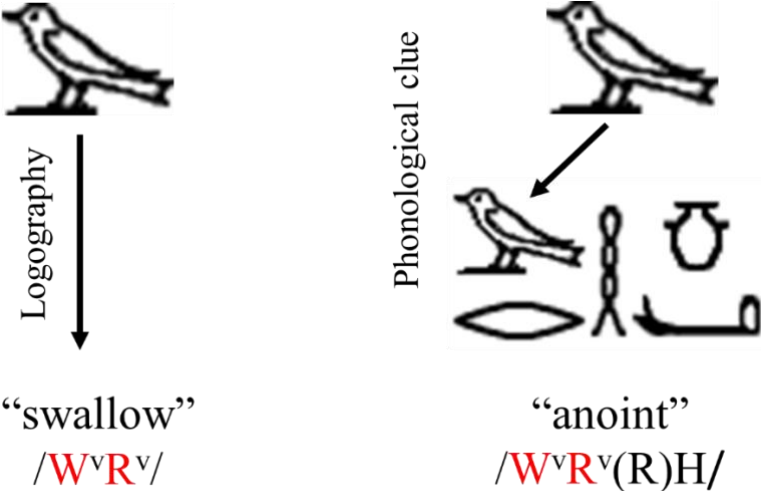
(2) Unique case of Egyptian writing system

However, there is another type of adaptation of writing to polysyllabic languages beyond merely segmenting the word into syllables and representing these syllables. This adaptation is

exemplified by Egyptian hieroglyphic writing. The origin of this writing remains a topic of ongoing debate: is it an instance of the first full writings, or was it influenced by the Sumerian model? As a logographic script, Egyptian writing is at least as old as Sumerian. Grammatologists are divided on whether Egyptian reached the status of a full writing system on its own or with the influence of Sumerian. Egyptian, being a polysyllabic language with many consonants and few vowels, encountered challenges similar to those faced by the Japanese or Akkadian languages. Yet, the core structure of hieroglyphic writing mirrors that of Chinese and Sumerian: it constructs hieroglyphic groups from a set of logograms, integrating information about both the signifier and the signified. The challenge for this system was to select logograms that could effectively convey information about the signifiers of words, especially in a language with a low rate of homophony. To address this, the Egyptians devised a strategy of using approximate homophony, maintaining the syllables' onsets while omitting the vowels. For example, the word /W^vR^v(R)H/ “anoit” (where “v” symbolises one of the three Egyptian vowels) is depicted using the hieroglyph /W^vR^v/, which captures the phonological onset of the word (see Figure 1.10).

Figure 1.10

Example of using an Egyptian word as a phonological clue to form a new Egyptian word



Perhaps more so than in Chinese or Sumerian, the phonological grapheme in Egyptian seems not to denote a linguistic unit but rather to provide the reader with an indication of the word's pronunciation. Indeed, in the example given in Figure 1.10, each of the three graphemes on the left offers (sometimes redundantly) clues about the pronunciation of the word (some authors refer to this as a "consonantal skeleton"). The two graphemes on the right convey semantic information. Thus, three types of graphemes provide phonological information: those corresponding to three consonants, to two consonants, and to a single consonant. Some authors have referred to this last set of graphemes as the "Egyptian alphabet".

(3) Transition to western semitic writing systems

The influence of Egyptian on the creation of new scripts has been significant, especially with Semitic scripts. The ancient Semitic scripts of the west, such as Phoenician and Aramaic, adopted the Egyptian uni-consonantal phonological graphemes. Semitic languages share common features with Egyptian: they are polysyllabic and possess few vowels. Words in these languages are constructed around roots composed of three consonants ("consonantal roots") with the addition of a "vowel pattern". Therefore, the "Egyptian alphabet" was well-suited for writing these languages. There is a notable disagreement among scholars regarding the definition of the inner structure of the ancient Semitic scripts, a disagreement which seems irresolvable. Ritner (1996) has acknowledged the controversial nature of the term "alphabet". Some scholars argue that since the Semitic script, which is primarily consonantal and does not fully notate vowels (thus being an abjad, according to Daniels, 1990) and prior to the development of a more or less independent system of diacritics, does not constitute a "true alphabet" but rather a *syllabary*. This view, initially advanced by Gelb (1974), suggests that each sign of a syllabary represents a syllable. Whereas syllabaries like the Ethiopic, Indic, and

Japanese fully represent a syllable, the Semitic syllabaries signify the initial consonant of the syllable while leaving the remainder unspecified.

However, if one discards the hypothesis that graphemes directly represent linguistic units, a clearer understanding of these scripts might emerge. Moreover, it is counterintuitive to assume that graphemes represent consonants, given that these linguistic units are unpronounceable on their own.

An alternative hypothesis might be that the graphemes of ancient Semitic scripts offer clues about either the sign (the “consonant root”) or the syllable. Under this hypothesis, the same graphemes could serve dual functions: a group of three graphemes might indicate the “consonant root”, while individually, a grapheme would offer approximate phonological information about the syllable.

However, Indian, European, and Korean languages have more diversified syllabic structures, especially a greater number of vocalic sounds. As a result, it became necessary to adapt the ancient Semitic scripts by introducing more information to denote syllables, and in particular by adding graphemes to represent vowels. At this stage of script adaptation, three distinct types of writing are generally recognized: abugida, alphabet, and featural writing (see Daniels & Bright, 1996). However, the logic of the analysis of the inner structure that we have presented suggests that these three types of writing share the same inner structure.

According to the traditional hypothesis, the alphabet stands distinct from all preceding writing systems. The inner structure of the alphabet is characterised by a direct correspondence between graphemes and phonemes. Daniels (2017) highlights the adaptability of abjads to Semitic languages due to their consonantal roots and vowel patterns. He contrasts this with the reduced suitability of abjads for Indo-European languages, where vocalisation is less predictable. In Daniels’ perspective, two distinct methods evolved for the obligatory notation of vowels.

The first, witnessed in the initial attempts to write Greek with the Phoenician abjad around 800 BCE, appears to have been both accidental and inevitable. Daniels illustrates how Semitic, with its larger consonant repertoire than Greek, repurposed letters (especially those representing laryngeal sounds absent in Greek) to indicate subsequent vowels. This gave birth to the alphabet, with discernible correspondences in both the letter shapes and their order.

Daniels (2017) also details a second Indo-European adaptation of the Semitic abjad that occurred in India, likely no earlier than the third century BCE. Instead of using separate letters for vowels, this adaptation added markers – to the left, right, above, or below consonant letters – to indicate the vowels and diphthongs inherent to Indic and Dravidian languages. He terms this adaptation an *abugida*.

This concept, however, raises a number of objections. Firstly, there is the matter that graphemes are associated with linguistic units that cannot be pronounced in isolation, namely the consonants. Advocates for the grapheme-phoneme correspondence hypothesis maintain that, even if phonemes are abstract units, they still have mental representations. Faber (1992) underscores the circular nature of the argument surrounding the intrinsic segmentation in alphabetic writing. She suggests that while alphabetic writing is fundamentally based on a phonological unit, which may not inherently be considered a natural, its existence attests to the naturalness of this segmentation. The paradox can be reconciled by emphasising that such writing could not have emerged if its foundational segmentation were not a natural process. Consequently, the very existence of alphabetic writing serves as evidence affirming the naturalness of phonological segmentation (p. 28).

Furthermore, if the letters of the alphabet represented phonemes, the spatial arrangement of the letters should systematically follow the order of sound utterance, which is generally the case. However, there are counterexamples. Faber (1992) illustrates this by pointing out that in “phonetic languages” like Spanish, the sequence of letters does accurately reflect the sequence

of spoken sounds. In contrast, the orthography of English does not maintain this linear relationship. Faber provides the example of the words “cop” /kɒp/ and “cope” /kɒp/, where the contrast in the medial vowels is orthographically expressed through the presence of a final “-e” in the latter. Therefore, the vowel /o/ is depicted by the non-linear, discontinuous sequence of letters “o-e” (p. 32).

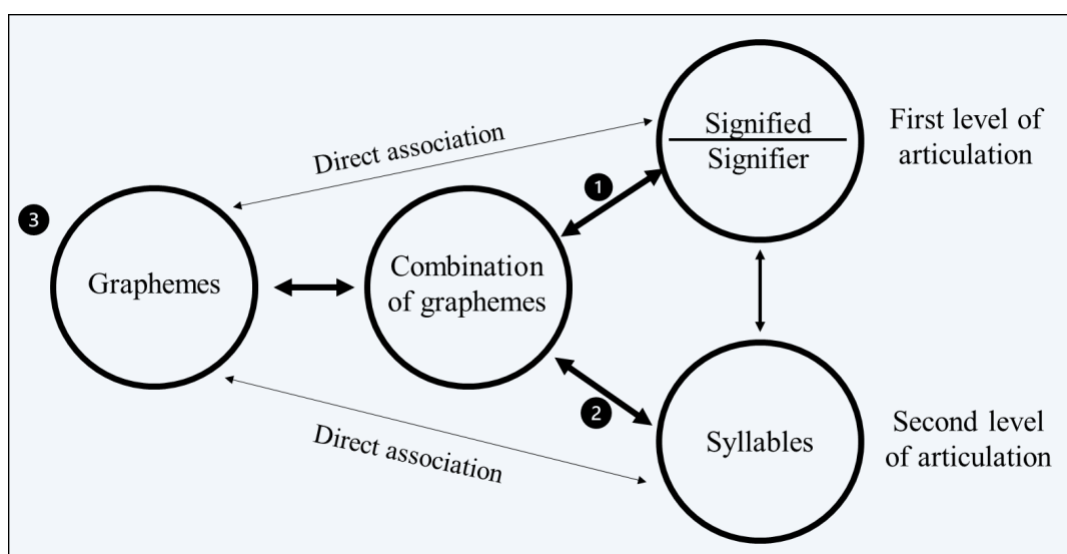
However, there is no reason for the alphabet not to follow the principles of the inner structure of writing systems as they were established originally and applied by all other scripts.

(4) Inner structure of alphabets

We have observed that the principal distinction between the writings of monosyllabic languages and polysyllabic languages (with the exception of Egyptian) revolves around the utilisation of denotation, in addition to the first level of a second level of articulation: the syllable. The cognitive mechanisms governing the correspondence between speech and writing involve the direct association and combination of graphemes. Graphemes fulfil two functions: they either directly denote the word or syllable or are employed as indices facilitating the retrieval of the sign or syllable. The adaptation of Semitic writings to other languages, which exhibit more vocalic variability in their syllables, entailed augmenting the indices necessary for recovering the syllable. We hypothesise that the identical process underpinned the creation of Indian (specifically, Brahmi) and Greek writings, followed by Korean, thus they share the same inner structure. So, we hypothesise that the inner structure of the alphabet is identical to that of syllabaries and corresponds to that described in Figure 1.11.

Figure 1.11

Inner structure of writing systems: A cognitive approach



Note. The relationships between graphemes and units of articulation are outlined through two types of Orthography: (1) Sign orthography and (2) Syllable orthography. (3) *Graphics Engineering* refers to the method by which graphemes representing units of articulation are presented.

The way in which graphemes are linked to articulation units is governed by orthography. The orthography in a script represents not only the set of direct associations between graphemes and units of articulation but also, more crucially, the combinations of graphemes that denote units of articulation. For instance, in French, the vowel letter “a” is directly associated with the syllable /a/ and the sign “a” (indicative of the French verb “avoir”, meaning “to have” in English). However, most of the connections between graphemes and units of articulation are through combinations of graphemes. Nearly all of the syllables and words in French are obtained by combining graphemes (see Figure 1.11). Syllabic orthography is generally systematic and regular. For example, in French, the syllables /fa/, /fy/, /fã/ etc. are denoted by the respective combinations of the graphemes “cha”, “chu”, and “chan”, etc. There are some

exceptions like the sound /s/ followed by a vowel: which can be written as “sa”, “ça”, “se”, “ce”, “si”, “ci”, “so”, “su” etc. Polysyllabic words are therefore very often written with regular grapheme combinations. However, and this mainly concerns monosyllabic words, sign orthography is much more variable. The origin of this variability is homography: as we saw with the earliest scripts, while homophony may be acceptable, the ambiguity associated with lexical homography is resolved by the addition of graphemes. Alphabetic scripts use precisely the same procedure. In French, there are very few homographs, and the spelling of homophonic words is systematically completed with additional graphemes (what DeFrancis calls “logographic information”). For instance, the words “chant” and “champ” (both pronounced /ʃɑ̃/) are not written “chan” but are represented by the combinations of the graphemes, respectively. Thus, one can say that there are two types of orthography systems in French: a relatively regular system for spelling polysyllabic words and a more irregular or ad hoc system for monosyllabic words.

The last aspect of our analysis concerns the spatial arrangement of grapheme combinations. While this does not relate directly to the internal structure, it pertains to what might be termed “graphic engineering.” We saw earlier that the creators of writing arranged graphic elements in a spatial order that respected the temporal sequence of articulation units’ enunciation. For example, the order of logograms follows, in the earliest logographic writings, the pronunciation order of the words. Conversely, the order of graphemes corresponding to the clue of an unit of articulation might adhere to different standards. For instance, in Chinese, the arrangement of graphemes forming the sign (i.e., compound characters) varies. The grapheme offering a phonological hint might be positioned to the right, left, below, or even around or inside the semantic grapheme. The same variability applies to the graphemes composing the syllable. In Japanese and Semitic scripts, a syllable often corresponds to a singular grapheme, with diacritics inside or around the main grapheme indicating syllabic sound shifts. Indian and

Ethiopian scripts borrowed from the graphic engineering of Semitic scripts, adding diacritics to the foundational syllabic akshara. For these scripts, graphemes assisting in identifying the syllable form a visual unit. Alphabetic scripts differ significantly in graphic engineering, with graphemes arranged linearly. The reasons for this linear choice are unclear. The commonly accepted hypothesis is that Greek writing, with the systematic addition of graphemes denoting vowels, constitutes a complete and refined segmental script. However, this hypothesis is not very credible since, as we have seen, the writing of vowels already existed occasionally in some Semitic scripts. Writing vowels actually responds to the need to provide more information on the syllable's identity, a need found in Indian scripts and Ethiopian writing. It therefore seems more likely to us that the choice of linear grapheme arrangement is due to other factors. For instance, Greek might favour linearity due to its common syllables composed solely of a vocalic nucleus. However, linear writing possibly eased the later formalisation of the phoneme concept, even though this concept emerged in Europe only in the late 19th century, millennia after alphabetic writing's advent.

The Korean script, Hangul, was created in the middle of the 15th century. Like Greek, it is composed of letters known as Jamos. Unlike linear arrangements, these letters are grouped into "blocks" reminiscent of Chinese writing's graphical style. For instance, the word "Hangul" combines the letters ㅎ(H), ㅏ(a), ㄴ(N), ㄱ(K, G), ㅡ(eu), and ㄹ(R/L) into two visually distinct sets, representing the word's two syllables: 한글.

Conclusions

This chapter offers an initial exploration into analysing the world's writing systems through the lens of cognitive mechanisms that enable the visual representation of speech. The evolution of a full or modern writing system was a gradual process, culminating in its ability to effectively represent speech. Central to this evolution was the assimilation of speech's

productive or generative nature. To achieve this, writing adhered to a fundamental linguistic principle: the articulatory nature, as described by Martinet (1960/1964). The invention of writing can be attributed to peoples whose primary linguistic structure was monosyllabic, allowing their scripts to be productive by using only one level of articulation: the Saussurean *sign*. However, adapting these scripts to other languages necessitated the introduction of a second level of articulation: the syllable. Despite the varied forms of these syllabic scripts, they all rely on the two cognitive mechanisms present in the earliest writings: direct association and combination of graphemes. Several factors, including the nature of neighbouring scripts such as Chinese, Sumerian, and Egyptian, influenced the form and orthography of these scripts. However, what most influenced the orthography of these different scripts is the complexity and variability of syllabic sounds. The more complex the syllables, the more information is needed to recover the syllabic sound, and therefore, the more complex is the combination of graphemes.

Studying the inner structure of writing systems is crucial for a deeper understanding of the cognitive mechanisms that underlie reading acquisition. Some general principles can be stated based on the mechanisms used by various writing systems. One key observation is that the proportion of direct associations to grapheme combinations indicates the complexity of learning a writing system. For instance, writing systems like Japanese or Hebrew, which heavily rely on direct associations between graphemes and speech sounds, tend to be easier to learn than scripts like Chinese or alphabetic ones.

Furthermore, the nature of a writing system can significantly influence its learning curve. Writing systems that are more consistent and regular, such as those with syllabic orthography, tend to be easier to learn than those with orthographies based on monosyllabic words. This notion aligns with discussions about the “orthographic depth” (Katz & Frost, 1992; Frost et al., 1987). It suggests that languages with numerous monosyllabic morphemes may present greater learning challenges than those with fewer.

Lastly, the graphic accessibility of the speech units denoted by the graphemes can play a significant role in learning correspondences between graphemes and the articulation unit. A clear visual distinction in scripts makes it easier for learners to associate graphemes with their corresponding speech sounds. For instance, the visual units in Chinese are more distinct than in ancient Sumerian or Egyptian scripts. Similarly, the block structure of Korean Hangul offers a clearer visual distinction than linear alphabets.

The exploration of the inner structure of writing systems in this chapter lays the groundwork for the primary focus of this thesis: understanding how children initially learn to read.

CHAPTER 2: EXPLICIT AND IMPLICIT ASPECTS IN LEARNING TO READ

This chapter provides a brief overview of the existing literature on explicit instruction and statistical learning in the context of reading acquisition. For explicit instruction, we distinguish between its “explicative” and “mnemonic” dimensions, highlighting that the latter often involves associative learning of orthographic-phonological pairs. Such learning might provide a conducive environment for subsequent learning mechanisms, such as statistical learning. In the discussion on statistical learning, the concept is introduced, followed by an exploration of its assessments and a discussion of the potential connection between assessed statistical learning ability and reading proficiency. Lastly, if such a connection exists, the chapter will explore the possible pathways linking statistical learning to reading ability.

PLAN OF CHAPTER 2

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Almost all neurotypical children acquire the rules of their spoken language from a very early age without any formal instruction, a process which occurs naturally and implicitly. However, learning to read generally involves a long and complicated process and requires considerable effort from children. Recognising this, scholars have sought to identify potential sources of difficulty of reading acquisition and to help children overcome these through appropriate explicit instruction. However, there is limited understanding of how explicit instruction influences the learner's cognitive processes. To gain deeper insights into the impact of explicit instruction on learning mechanisms, we need to provide initially a comprehensive description.

Explicit instruction

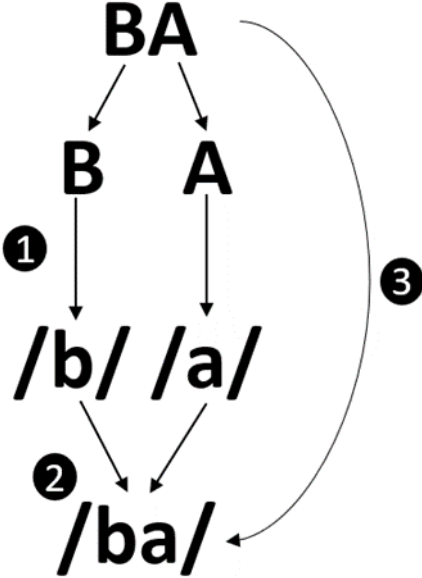
At its core, explicit instruction is a structured and systematic method of teaching that emphasises direct explanation. Upon overviewing explicit instruction in the early stages of learning to read an alphabetic writing, much of the instruction revolves around clearly explaining how this writing functions. For instance, the commonly suggested *phonics* approach focuses on elucidating the mechanics of alphabetic writing systems. Central to this is the alphabetic principle: the visual symbols of the writing system (graphemes) represent the sounds of the language (phonemes).

Figure 2.1 illustrates a basic *phonics* instruction scenario. This instruction provides an explicit explanation of the principles of alphabetic writing. When learners are taught that the letters “B” and “A” correspond to the sounds /b/ and /a/, respectively (as depicted in item 1 in Figure 2.1), the intent is to familiarise them with the alphabetic principle. Likewise, by explaining that combining the letters “B” and “A” produces the sound /ba/ (as shown in item 2 in Figure 2.1), we introduce the concept of phoneme blending.

While significant emphasis is placed on explaining explicitly the alphabetic principle to children, there is often insufficient acknowledgment of the simultaneous demand for them to memorise associations between letters or letter combinations and corresponding speech sounds. This requirement can be interpreted as an associative learning task. For instance, when children receive instruction that the letters “B” and “A” correspond to the sounds /b/ and /a/, respectively, they are implicitly expected to stock the pairs B-/b/ and A-/a/ in memory. A further, often overlooked, aspect of this learning process involves blending sounds to form phonological syllables. For instance, as depicted in item 2 of Figure 2.1, when children are instructed to blend the sounds, they are also expected to memorise the association BA-/ba/, as illustrated in item 3 of the same figure.

Figure 2.1

Schematisation of phonics instruction with an example “b.a.-ba”⁵



⁵ In French, the term “b.a.-ba” is used to refer to the most basic elements or principles of a subject or skill — the absolute basics or the fundamentals. This term originates from the analytic phonics instruction, which is based on combining two sounds /b/ and /a/ to form a syllable /ba/. However, what might be “b.a.-ba” for a literate person can be a complex multi-component task for a preliterate child.

Note. The numbers are labelled with three learning processes: ¹ sounding out phonemes corresponding to graphemes, ² blending phonemes to form a phonological syllable, ³ reading whole phonological syllables.

Upon analysing the multi-component nature of *phonics* instruction, we can distinguish two dimensions of explicit instruction. The first dimension is *explicative*, that is to explain the mechanics of writing systems. The second dimension is *mnemonic*, that is to prompt learners to memorise associations between different sizes of written symbols and linguistic units. Frequently, these two types are combined in the explicit instruction provided to prereaders. The primary objective of this thesis is to investigate the influence of *mnemonic* explicit instruction on subsequent cognitive learning processes, such as statistical learning.

Explicative dimension

Research has extensively focused on the first aspect of explicit instruction in learning to read. According to the classical conception of the inner structure of alphabetic writing, graphemes are supposed to directly denote phonemes. Therefore, the core in explaining the mechanics of alphabetic writings is to explicitly convey to prereaders that letters or letter strings correspond to abstract sounds, known as phonemes.

Thus, the design of *explicative* explicit instruction is motivated by the challenges children face while learning the correspondence between graphemes and phonemes. Liberman (1973) pointed out that the complex and inconsistent mappings between graphemes and phonemes, as seen in English, might complicate the learning of associations between them. Scholars defines writing systems with deep orthographic as having a high level of orthographic depth (Frost et al., 1987).

Importantly, Liberman (1973) noted that the difficulty at the beginning of learning to read lies in the abstract nature of phonemes, particularly consonants. Due to this abstract nature, the consonants are sometimes followed by a vocalic schwa /ə/ when they are pronounced individually (e.g., the letter “t” is pronounced as /tə/). This complicates the blending of phonemes. For instance, when prereaders are asked to blend sounds /b/, /a/, and /t/ to form a syllable, they would say /bə.a.tə/ instead of /bat/.

Liberman and colleagues (1973; 1974) thought that the solution is to make children be aware of phonemic segments of speech so that they would understand that phonemes are abstract units rather than tangible objects. It is thus suggested to train firstly children with phonemic awareness, defined as the conscious capability to manipulate language sounds. Phonemic awareness training encompasses a range of tasks, including phoneme identification, counting, elision, and blending (for a review, see, for instance, see Sodoro et al., 2002). Numerous studies have shown that the training of phonemic awareness facilitates the alphabetic principle (e.g., Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1990).

Furthermore, *explicative* explicit instruction involves the direct explanation of letter knowledge, encompassing both the name and sound of a letter⁶. Learning letter names can enhance understanding of the alphabetic principle, particularly when letter names embody their associated sounds (e.g., Treiman et al., 2008; Treiman et al., 1998). Notably, there is a bi-directional relationship between phonemic awareness and letter-name knowledge. For instance, a prereader’s initial letter-name knowledge has been found to predict subsequent growth in phonological awareness, and the inverse is also true (e.g., Lerner & Lonigan, 2016). Similarly, training in phonemic awareness can further facilitate the understanding of the alphabetic principle, thereby enhancing reading skills, and learning to read has been associated with gains

⁶ Teaching letter names and sounds also has a *mnemonic* aspect, requiring children to memorise both the letter’s name and its sound.

in phonemic awareness (e.g., Bentin & Leshem, 1993; Burgess & Lonigan, 1998; Tunmer & Rohl, 1991). Given the progression towards accessing phonemic units, the subsequent logical step is phonics-based explicit instruction (e.g., Castles et al., 2018; Ehri et al., 2001; Rayner et al., 2001).

Systematic phonics instruction aims to teach children the relationships between graphemes and phonemes. The underlying premise is that gaining a foundational understanding of these correspondences equips children with the skills to decode most words in their language. Commonly, phonics instruction is categorised into analytic and synthetic approaches. The analytic approach introduces children to whole words or written syllables first, guiding them to segment these into their component grapheme-phoneme correspondences. Conversely, the synthetic approach first teaches grapheme-phoneme correspondences individually and then instructs children to blend these to produce whole words or syllables.

Another attempt to give an *explicative* explicit instruction concerns the explicit explanation of the *principle of phonetization*. Gleitman and Rozin (1973) identified a potential source of difficulty in learning to read: some children have difficulty in understanding that orthography indirectly mediate meaning through sound systems. For instance, the barrier manifests as a difficulty in distinguishing between words with different written lengths (e.g., “mow” and “motorcycle”) based on the sounds they represent. To assist children in understanding that a sign represents a sound, and also to avoid the difficulty related to the abstract nature of phonemes, Gleitman and Rozin (1973) conducted a study in which they taught children a *syllabary* consisting of about twenty images (e.g., the syllable /pen/ was represented by an image of a pen). The results were spectacular: the children learned the associations very quickly and were then able to read new words composed of known letters and associations of learned image-syllable pairs (e.g., after learning the association image of a pen-/pen/, reading /open/ when seeing O-image of a pen). However, although the children easily learned written

sign–oral syllable associations and were able to use them to decipher words, they still encountered just as much difficulty in making associations at a finer level, between letters and phonemes. This suggests that comprehending the *principle of phonetization* may not be the primary hurdle in learning to read.

Mnemonic dimension

Explicit instruction in reading inherently possesses a *mnemonic* dimension. A salient illustration is how elucidating the *alphabetic principle* necessitates the memorisation of grapheme-sound pairs. Additionally, both analytic and synthetic phonics instructions demand memorisation of associations between letter strings (or words) and phonological syllables. Consequently, every explicit instruction entails memorising the relationships between orthographic and phonological representations, which can be conceptualised as associative learning. While the explanation—a precise and lucid description provided by a literate instructor—concerning the mechanics of alphabetic writing is often deemed as the foundational learning component, the significance of memorising orthographical-phonological pairs as a precursor to unconscious learning mechanisms has been overlooked. Recognising the impact of this associative learning on unconscious mechanisms, such as statistical learning, is crucial.

In the literature, the *mnemonic* dimension in explicit instruction has not been especially considered, but only accidentally considered by the debate between the *phonics* approach and the *whole-language* approach. The nature of the debate concerns the size of orthographic-phonological pairs that should be learned. The *phonics* approach highlights the learning of grapheme-phoneme correspondences, by arguing that acquiring these correspondences equips children with the skills to decode most words in their language. The *whole-language* approach advocates teaching entire words directly, fostering a child’s discovery of meaning through immersion in a literature-rich environment (Goodman, 1967; Smith, 1971).

While much preference in the literature is attributed to the phonics-based approach, it seems that the syllable approach has been abandoned. This oversight might be partly due to the partial failure of the approach by Gleitman and Rozin (1973). However, their study is not a negative example of the syllable approach, given the lack of use of syllable letters. In their study, the children perfectly retained that the image of a pen corresponded to the sound /pen/, but nothing in the drawing suggested to them that /pen/ is composed of three phonemes represented by the letters “p”, “e”, and “n”. While the association mechanism was facilitated by the use of easily identifiable visual signs associated with syllables, the absence of letters during associative learning did not allow for the triggering of another equally important mechanism: the association of letters with syllable sounds. Accidentally, this study implies the importance of including both orthographic and phonological representations in associative learning. We can hypothesise that the act of memorising associations between visual elements and speech sounds establishes a network of connections between mental representations of letters and their corresponding phonological representations. This interconnected framework offers the brain, or the broader cognitive system, a conducive environment. Within this environment, the system is primed to detect and extract underlying patterns and regularities through statistical learning.

Statistical Learning

In our daily life, we are constantly surrounded by a diverse array of objects, people, events, and places. Often, we find ourselves identifying patterns in our surroundings, even without intentional effort or conscious awareness. For instance, one noticed green leaves under the ice on an early snowy autumn day, which he found somehow unusual but could not pinpoint why. This reaction can be attributed to an establishing pattern he formed over time, associating the onset of snowy, icy weather with the presence of withered yellow leaves—a pattern repetitively observed. This learned association is a manifestation of the brain’s ability to pick

up on consistent patterns and discern irregularities or exceptions based on those established patterns.

Definition

There are two related bodies of research literature on this phenomenon: statistical learning and implicit learning. The definitions of statistical learning and implicit learning are influenced by the first studies that used these terms (implicit learning: Reber, 1967; statistical learning: Saffran et al., 1996). Reber (1967) introduced the concept through studies that demonstrated that individuals could learn complex structures without being aware of the rules governing those structures. Specifically, participants were exposed to strings of letters generated using artificially created grammars. Participants learned to judge the grammaticality of new strings correctly, even though they could not verbalise the rules that defined grammaticality. This type of learning was “implicit,” meaning it occurs without explicit instruction or conscious understanding of what was being learned.

The first studies on statistical learning were conducted by Saffran and colleagues, who demonstrated that infants can segment an artificial continuous stream of speech sounds into its component syllabic sequences, based on the transitional probabilities between syllables (Aslin, Saffran et al., 1998; Saffran et al., 1996). Statistical learning is defined as the ability to extract statistically structured patterns from sensory input, and this occurs without explicit awareness of the underlying patterns. Given the implicit nature of statistical learning, the line between statistical learning and implicit learning is sometimes unclear. Some authors have argued for the integration of implicit learning and statistical learning and proposed the combined term “implicit statistical learning” (Christiansen, 2019; Conway & Christiansen, 2006; Perruchet & Pacton, 2006). In the current study, we do not distinguish between statistical learning and

implicit learning; instead, we use “statistical learning” as a general term to refer to the ability to pick up on regularities from the environment.

Over the past two decades, researchers have expanded their interest to include the role of statistical learning in the process of learning to read (Arciuli & Simpson, 2012). Writing systems, such as English and French, are often characterized by highly complex mappings between spellings and sounds. They frequently convey various types of information, including phonology, semantics, and morphology, making it seemingly impossible to convey all of this information explicitly. It is highly likely that statistical learning is involved in the process of learning to read.

The current project aims to investigate the involvement of statistical learning in the initial stages of learning to read, specifically during the acquisition of core knowledge—namely, grapheme-phoneme correspondences. Before delving into the details of the current study, I will provide a brief overview of research on statistical learning. First, I will address how statistical learning is assessed in the literature, followed by an exploration of whether the statistical learning ability assessed by these methods is linked to reading ability. Finally, I will discuss the possible pathways through which statistical learning may be linked to reading ability, if such a link exists.

Assessments of statistical learning

As mentioned above, research on the implicit assimilation of regularities is incorporated into the literature on implicit learning research before the introduction of statistical learning as a cognitive mechanism.

The artificial grammar learning task was originally used to assess rule learning (Reber, 1967). It is generally accepted that the task is used to probe implicit learning⁷ (Dienes et al,

⁷ We keep the term “implicit learning” here as it was originally utilised by the authors.

1991). In this task, participants are presented with strings of letters or symbols generated according to a miniature grammar (i.e., a set of rules). Some combinations of letters or symbols adhere to this grammar, while others do not. Initially, participants are asked to perform a cover task, which involves memorising the strings of letters or symbols for subsequent recall. Following the exposure phase, participants are informed that the strings they were exposed to were created based on a set of rules; however, they are not told what these rules are. Subsequently, participants are shown a new set of sequences, some of which are “legal” (i.e., follow the rules) and some of which are “illegal” (i.e., do not follow the rules). They are asked to identify the legal sequences. This task measures their ability to generalise the underlying structure of the grammar.

The serial reaction time is also used to test implicit learning (Nissen & Bullemer, 1987). In this task, participants are shown visual stimuli at different positions on a screen and are asked to press a button corresponding to the location as quickly as they can. Unbeknownst to the participants, during structured blocks, the sequence in which the stimuli appear is repetitive. As participants implicitly learn this sequence, their response times become progressively faster. At the end of the experiment, a control block is introduced where the order of stimuli is randomized. If implicit learning has taken place, participants will make more errors and their reaction times will increase in this block. The extent of learning is then gauged by comparing performance in the control block to that in the structured block.

Since the seminal study by Saffran et al. (1996), statistical learning has been studied as a theoretical construct that emphasises the process of learning statistically structured regularities embedded within sensory input. Numerous studies have replicated this task to assess the ability for statistical learning. Typically, this task involves presenting a continuous stream of auditory or visual stimuli that contain embedded sequences (e.g., a triplet of abstract forms). These sequences have high transitional probabilities between their components and

lower transitional probabilities at their boundaries. In the familiarisation phase, participants are exposed to this stream of stimuli. This is followed by a test phase where participants are required to choose between the embedded patterns and foil patterns. Bogaerts et al. (2020) summarise this type of task as the *statistical learning embedded-pattern task* (SL-EPT). The task was widely used across different sensory inputs: auditory, visual, and integrated auditory-visual modalities (for a review, see Conway & Christiansen, 2005; for more recent reviews, see Bogaerts et al., 2020; Frost et al., 2019; Frost et al., 2015). Participants have exhibited sensitivity to a variety of auditory stimuli, including pure tones (e.g., Gabay et al., 2015; Saffran et al., 1999), speech syllables (e.g., Evans et al., 2009; Gabay et al., 2015; Lammertink et al., 2020). In terms of visual stimuli studies have tested statistical learning using abstract shapes (Fiser & Aslin, 2001; Turk-Browne et al., 2005; Turk-Browne & Scholl, 2009), unfamiliar pictures (Arciuli & Simpson, 2011; 2012), and coloured circles (e.g., Singh et al., 2018). There has been also research presented integrated auditory-visual modalities (i.e., correspondence between a visual stimulus and a auditory stimulus) to explore the role of statistical learning in understanding phonetic regularities in Chinese characters (He & Tong, 2017; Tong et al., 2020).

Statistical learning and reading ability

Using the range of statistical learning methods reviewed above, previous studies have investigated the potential causal relationship between statistical learning and reading ability. To date, several studies have demonstrated a correlation between performance on statistical learning tasks and reading skills. Arciuli and Simpson (2012) assessed statistical learning using a stream of visual stimuli (i.e., alien figures) that embedded a triplet pattern. Their results suggested that English-speaking children and adults with a higher capacity for statistical learning also exhibited better reading abilities. Using a similar triplet paradigm, Torkildsen et al. (2019) demonstrated that performance on the statistical learning task predicted children's

reading ability in a semi-transparent orthography, specifically Norwegian. Another study tested English-speaking learners who were acquiring Hebrew as a second language (Frost et al., 2013). Here, performance on a visual statistical learning task correlated with both unpointed nonword and pointed word reading abilities. Beyond establishing the relationship between statistical learning and reading ability in a broad way, Spencer et al. (2014) found that statistical learning is related to several foundational literacy-related skills, including oral language, vocabulary knowledge, and phonological processing. Mainela-Arnold and Evan (2014) reported that the ability for statistical learning likely correlates with lexical-phonological, but not lexical-semantic abilities.

However, not all findings have reported a correlation between statistical learning and reading ability. Nigro et al. (2015) assessed statistical learning using an untaught graphotactic rules learning task. The results indicated that while Spanish-speaking children could generalise the rules, their performance on this task did not significantly correlate with their reading ability. The authors suggested that the Spanish writing system has minimal inconsistencies in phoneme-grapheme mappings. As a result, the statistical learning ability of graphotactic rules might be particularly tied to these few inconsistent patterns. Schmalz et al. (2019) also failed to find a significant correlation between performance on serial reaction time and artificial grammar tasks and reading abilities in adults. They speculated that the inconsistent results compared to previous studies might stem from differing methods of assessing statistical learning.

Indeed, the current evidence suggests that the dimensions of statistical learning still require empirical discussion. Recent studies tend to view statistical learning as a multifaceted individual ability, and different statistical learning tasks may tap into varying components of statistical learning (Arciuli, 2017; Bogaerts et al., 2022; Siegelman et al., 2017). It is suggested that which specific component in statistical learning is tapped should be discussed when selecting a statistical learning task (Qi et al., 2019).

Assuming that statistical learning is related to reading ability in a broad way, the next question is about the causal mechanisms linking statistical learning performance to reading proficiency.

Causal pathways leading statistical learning to reading ability

Previous studies have established the existence of some link between statistical learning and reading ability. The possible causal pathways could be through the sensitivity to orthographic regularities (e.g., Chetail, 2017; Cassar & Treiman, 1997; Gingras & Sénéchal, 2019; Pacton et al., 2001; Treiman & Kessler, 2013), the assignment of lexical stress during word recognition and reading (e.g., Arciuli & Cupples, 2006; Arciuli et al., 2010; Mousikou et al., 2017), and morphological processing (e.g., Lelonkiewicz et al., 2020, 2023; Ulicheva et al., 2020).

Importantly, statistical learning can be related to reading ability by enabling the implicit assimilation of regularities between phonology and orthography, which constitutes the core knowledge when children start learning to read. In Chinese writing, studies have shown that children can induce phonetic regularities by implicitly analysing phonetic components in Chinese characters through exposure to character-sound correspondences (He & Tong, 2017; Tong et al., 2020; Yin & McBride, 2015).

In alphabetic scripts, statistical learning plays a crucial role in extracting the regularities of grapheme-phoneme correspondences. Statistical learning may enable readers to discern grapheme-phoneme correspondences based on their contexts in various deep orthographies. English, for example, is a deep orthography and exhibits complex correspondences between graphemes and phonemes (Schmalz et al., 2015). Consider the letter “c”; its pronunciation can vary depending on the context, that is, the letters surrounding it. In the word “cat” /kæt/, “c” is pronounced as /k/, while in “certain” /ˈsɜː.tən/, it is pronounced as /s/. Siegelman et al. (2020)

employed a word naming task, manipulating orthography-phonology regularities, to assess each child's reliance on these regularities. The results highlighted individual differences in learning grapheme-phoneme correspondence regularities and revealed that English-speaking children with heightened sensitivity to these regularities exhibit enhanced reading skills.

Another noteworthy study is conducted by Apfelbaum et al. (2013), examine whether English-speaking first graders could learn grapheme-phoneme correspondence regularities simply through exposure to words and nonwords. The goal was for children to learn GPC regularities for six vowels that were embedded in different consonant frames (e.g., the mapping between “A” and /æ/ was embedded in words like “bat” /bæt/, “hat” /hæt/, and nonwords like “cal” /kæl/ and “gat” /gæt/). Children were divided into two groups; one group was trained with words and nonwords whose consonant frames were relatively variable, and the other group was trained with word and nonwords whose consonant frames were relatively similar. They found that superior learning was achieved when there was a higher degree of variability between the consonant frames. This result suggests that there may be ways to structure statistical learning in the classroom such that it is more effective. However, pretesting from this study showed that children started with a certain level of reading knowledge, and it is unclear whether the implicit assimilation of grapheme-phoneme correspondence regularities was derived through prior explicit phonics instruction. One of the main objectives of the current study is to address this gap in the literature: To what extent statistical learning allow children, before formally receiving phonics instruction, to extract grapheme-phoneme correspondence regularities from orthography and phonology associations.

CHAPTER 3: TOWARDS A THEORETICAL FRAMEWORK: RESEARCH QUESTIONS AND HYPOTHESES

This chapter introduces the research questions and corresponding hypotheses of the current thesis. Firstly, it presents the “syllabic bridge” hypothesis, suggesting that prereaders begin to learn to read by associating letter clusters with concrete phonological units, such as syllables. Secondly, the chapter discusses the study by Vazeux et al. (2020), which demonstrates that a syllable-based approach led to a greater increase in phonemic awareness than a phoneme-based approach. Thirdly, the chapter outlines how Guo et al. (2023) interpreted the results of Vazeux et al. (2020) by incorporating statistical learning. Finally, a theoretical framework is provided that accounts for the initial stages of learning to read. Based on this theoretical framework, two main research questions are posed, and the corresponding hypotheses are provided.

PLAN OF CHAPTER 3

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As argued in Chapter 1, we posit that the inner structure of writing systems lies in not only mappings between written symbols and linguistic units but also a combination of information to guide readers towards the units of articulation: sign. In the case of alphabetic writing systems, reading scientists adopt the classical inner structure of writing systems, which consists of mappings between a grapheme and a phoneme. As reviewed in Chapter 2, scholars have pursued this line of inquiry, studying how to teach the relationships between graphemes and phonemes explicitly and effectively, and ultimately, how to address the challenges children face when learning these relationships through explicit instruction. However, the mnemonic dimension of explicit instruction also requires also memorising orthographic-phonological associations, which might provide a conducive orthographic environment for statistical learning. It is logical to infer that the clues forming the units of articulation could be learned implicitly through statistical learning. This assumption can divert children from the sources of difficulty at the very beginning of learning to read, as discussed in Chapter 2. However, as shown in the overview of literature on statistical learning in Chapter 2, there has been no previous empirical study considering the potential involvement of statistical learning in acquiring grapheme-phoneme correspondences, particularly at the very beginning of learning to read.

This assumption, providing a conducive orthographic environment consisting of phonological-orthographic mappings, aligns with a perspective of learning to read known as the *syllable bridge* hypothesis (Doignon-Camus & Zagar, 2014). According to this hypothesis, learning to associate letter clusters with available phonological syllables might be the first step in learning to read. This chapter begins by exploring the origins of the *syllabic bridge* hypothesis.

Where does the *syllabic bridge* hypothesis come from?

The central claim of the *syllabic bridge* hypothesis posits that children can learn statistical properties of letter co-occurrences and spontaneously associate them with concrete and available phonological syllables to establish the syllabic connections.

This process of learning statistical properties of letter co-occurrences has been substantiated through a series of observations using the illusory conjunction paradigm. In an illusory conjunction task, a word is quickly presented with letters in different colours, and participants are asked to report the colour of a target letter. For instance, the word “ANVIL” is presented twice, either “ANvil” or “ANVil” (in which upper- and lower-case letters represent two different colors). Participants are instructed to detect a target letter (the letter “v”/“V” in the example) and to report its color (the letter “v”/“V” in the example). Prinzmetal et al. (1986, 1991) have robustly shown that adults made more preservation errors (i.e., reporting the incorrect color of “V” in “ANVil”) than violation errors (i.e., reporting the incorrect color of “v” in “ANvil”). This result was assumed to reflect the influence of sublexical syllabic units on visual word perception.

To explore what information these syllabic perceptual units are built on, Doignon & Zagar (2005) compared the illusory conjunction error rates on two types of French words in adults. For congruent words (e.g., “MATIN”, meaning “morning” in English), the boundary of phonological syllables coincides with the orthographic boundary⁸. In this case, positional bigram frequencies determine the boundaries, such as the second bigram “AT” having a lower frequency than the third bigram “TI” in “MATIN”. In contrary, for incongruent words (e.g., “RUBAN”, meaning “ribbon” in English), the phonological syllable boundary does not coincide with the orthographic boundary. For instance, the second bigram “UB” in “RUBAN”

⁸ For the French word “MATIN”, the phonological syllable boundary MA/TIN aligns with the orthographic boundary MA*TIN.

has a higher frequency than the third bigram “BA”. The study found a higher preservation error rate for congruent words compared to incongruent words, with the difference being notably reduced for the latter. These findings suggest a cooperative interaction between phonological syllabic representations and orthographic redundancy in forming syllabic perceptual units.

How do associations between phonological and orthographic representations emerge during reading acquisition? Do they develop gradually with increased familiarity with spelling, or do they manifest early in the process of learning to read? Surprisingly, studies on illusory conjunction errors have revealed that the influence of orthographic redundancy is present from the first year of learning to read, and the intensity of this influence does not vary with reading level (Doignon & Zagar, 2006; Doignon-Camus et al., 2013). This finding indicates a process whereby children utilise the distributional properties of written language to cluster letters into concrete phonological units (i.e., syllables)—a phenomenon we term the *unitisation process*.

Further investigations with prereaders showed that a few minutes of presentation of letter co-occurrences (e.g., “NA”) enabled children to process letters as reading units (Doignon-Camus & Zagar, 2014), reflecting sensitivity to orthographic redundancy. Moreover, when letter clusters were displayed with the pronounced syllables they denoted, the unitisation process appeared more efficient than when they were displayed without hearing the pronounced syllables. Thus, prereaders are able to spontaneously associate letter clusters with phonological syllables, thereby building the *syllabic bridge*. In other words, the *unitisation process* is consolidated when the letter cluster is associated with a concrete phonological representation, i.e., syllable representation.

Syllable-first vs. phoneme first approaches

The effectiveness of constructing the *syllabic bridge* was later investigated by Vazeux et al. (2020), who conducted a comparative study between this *syllabic bridge*-based approach

and the phoneme-based approach. Notably, both the *syllabic bridge*-based approach and the phoneme-based approach acknowledge the pivotal role of developing phonemic awareness, which entails the manipulation of phonemes—a critical skill that serves as a foundation for reading (Adams, 1991). Phonemic awareness has been identified as the most robust predictor and precursor of literacy acquisition across various alphabetic systems (Castles & Coltheart, 2004; Hulme et al., 2005). In the study by Vazeux et al. (2020), phonemic awareness was used as an indicator of preliminary mastery of the alphabetic code among French-speaking prereaders. A cohort of 222 children were divided into two groups for a brief learning program: one group learned eight correspondences between letters and phonemes (see Table 3.1(a)), while the other group learned eight correspondences between letter strings and phonological syllables (see Table 3.1(a)). Notably, the learned letters-to-syllable associations and letter-to-phoneme associations consisted of the same grapheme and phoneme components. The results revealed that prereaders demonstrated greater improvement in phonemic awareness when learning letters-to-syllable correspondences rather than letter-to-phoneme correspondences (see T1 and T2 in Figure 3.1). Vazeux et al. (2020) introduced a short session on coding and decoding after either letter-to-phoneme or letters-to-syllable associative learning. The results showed that the letters-to-syllable group kept its advantage in phonemic awareness after the alphabetic code session (see T2 and T3 Figure 3.1).

Table 3.1

Materials for the phoneme-based approach and syllable-based approaches

(a) Phoneme-based approach

| | |
|-------|-------|
| B-/b/ | A-/a/ |
| F-/f/ | I-/i/ |
| T-/t/ | O-/o/ |
| S-/s/ | U-/y/ |

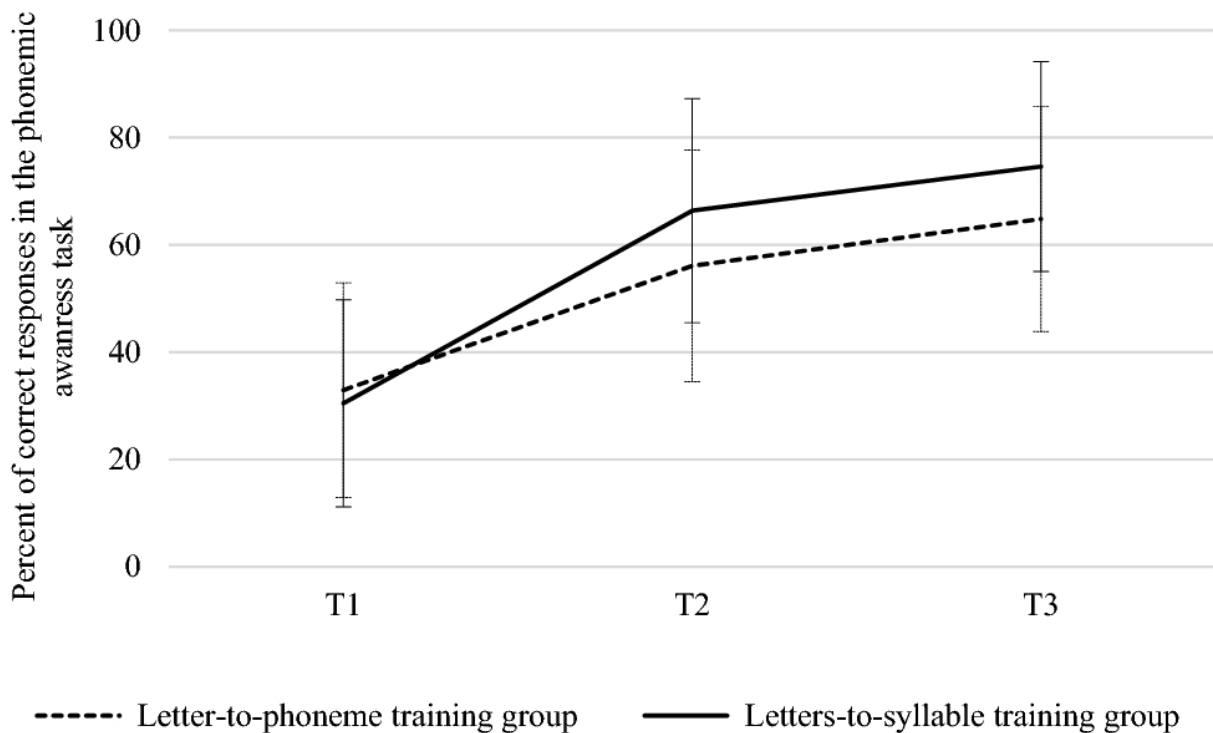
(b) Syllable-based approach

| Set 1 | A-/a/ | I-/i/ | O-/o/ | U-/y/ | | Set 2 | A-/a/ | I-/i/ | O-/o/ | U-/y/ |
|-------|---------|---------|---------|---------|----|-------|---------|---------|---------|---------|
| B-/b/ | BA-/ba/ | BI-/bi/ | | | | B-/b/ | | | BO-/bo/ | BU-/by/ |
| F-/f/ | FA-/fa/ | FI-/fi/ | | | or | F-/f/ | | | FO-/fo/ | FU-/fy/ |
| T-/t/ | | | TO-/to/ | TU-/ty/ | | T-/t/ | TA-/ta/ | TI-/ti/ | | |
| S-/s/ | | | SO-/so/ | SU-/sy/ | | S-/s/ | SA-/sa/ | SI-/si/ | | |

Note. The eight letters-to-syllable associations in the syllable-based approach use a *Latin square* design (set 1 and set 2).

Figure 3.1

Percentage of correct responses in the final phoneme elision task at T1, T2, and T3 for the letter-to-phoneme and letters-to-syllable training groups (Vazeux et al., 2020)



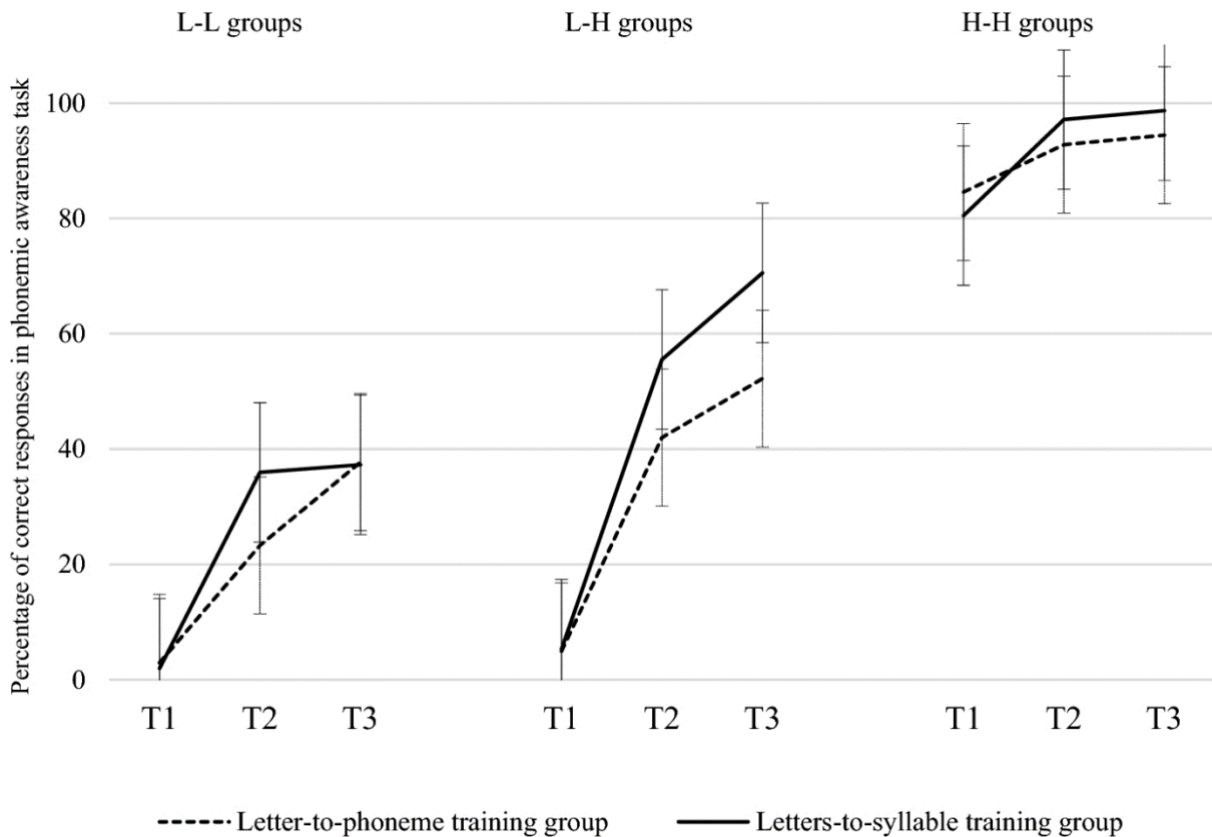
Note. T1, test before learning sessions; T2, after learning session and before coding and decoding instruction; T3, after coding and decoding instruction. From “Syllable-first rather than letter-first to improve phonemic awareness”, by M. Vazeux, N. Doignon-Camus, M-L. Bosse,

G. Mahé, T. Guo, and D. Zagar, 2020, *Scientific Reports*, 10, 22130, p.3 (<https://doi.org/10.1038/s41598-020-79240-y>). Copyright 2020 by Spring Nature.

When conducting a more detailed analysis of the preliteracy level of participants at the pretest, the participants were divided into four subgroups according to their initial level of letter name knowledge and phonemic awareness score. As illustrated in Figure 3.2, in each subgroup, the children trained with letters-to-syllable association made more progress than those trained with letter-to-phoneme associations. The tendency for progress in phonemic awareness diverged after coding and decoding instruction. Within the subgroup with low phonemic awareness but high letter name knowledge (L-H groups), the letters-to-syllable group consistently maintained their advantage in the progress on phonemic awareness. These results in L-H groups are particularly noteworthy given that the children were at a stage where they already possessed good letter name knowledge, enabling them to begin learning grapheme-phoneme correspondences. However, they had a limited level of phonemic awareness, so they needed to learn this skill, essential for grasping the alphabetic principle. This phase can be considered a critical moment for initiating the learning of reading. However, in the subgroup with low letter name knowledge and low phonemic awareness (L-L groups), the two training groups arrived at the same level of phonemic awareness after coding and decoding instruction. Within the subgroup with high letter name knowledge and high phonemic awareness (H-H groups), the two training groups continued to progress in phonemic awareness in parallel, but notably, the letters-to-syllable training group had almost reached the ceiling of the test. The results in the L-L groups are in line with the literature that highlights the importance of letter name knowledge when learning the alphabetic principle (e.g., Piasta & Wagner, 2010; Treiman et al., 2008).

Figure 3.2

Percentage of correct responses in the final phoneme elision task at T1, T2 and T3 for the subgroups characterised by their initial levels of phonemic awareness and letter name knowledge (Vazeux et al., 2020)



Note. L-L = low phonemic awareness/low letter name knowledge. L-H = low phonemic awareness/high letter name knowledge. H-H = high phonemic awareness/high letter name knowledge. From “Syllable-first rather than letter-first to improve phonemic awareness”, by M. Vazeux, N. Doignon-Camus, M-L. Bosse, G. Mahé, T. Guo, and D. Zagar, 2020, *Scientific Reports*, 10, 22130, p.5 (<https://doi.org/10.1038/s41598-020-79240-y>). Copyright 2020 by Spring Nature.

Vazeux et al. (2020) interpreted the significant progress on phonemic awareness in L-H groups by learning the letters-to-syllable associations along the lines of the “*prereaders could*

build phoneme representations in mirror of letters, and thereafter acquire and master the alphabetic code” (p.6). However, it remains unclear how phoneme representations would be built mirrored by letters, and this chapter aims to provide a theoretical framework accounting for how learning letters-to-syllable associations might facilitate the acquisition of the alphabetic principle. This theoretical framework led to the research questions posed in the current study.

Involvement of statistical learning to learn grapheme-phoneme correspondences

As reviewed in Chapter 2, statistical learning is likely linked to reading ability as it enables the detection and extraction of grapheme-phoneme correspondences from an orthographic environment (e.g., Apfelbaum et al., 2013; Siegelman et al., 2020). Here, we hypothesize that statistical learning is likely involved in learning the regularities of grapheme-phoneme correspondence from letters-to-syllable associations, even prior to explicit phonics instruction. The letters-to-syllable associations used in Vazeux et al. (2020) can be considered a simple and micro-orthographic environment (see Table 3.1(b)). Specifically, these letters-to-syllable associations are regular in French. The regularity of these correspondences is evident as the same letter always corresponds to the same phoneme. For example, the letter “B” in letter strings “BA” and “BI” always corresponds to the phoneme /b/, and the letter “A” in letter strings “BA” and “FA” always corresponds to the phoneme /a/. As children assimilate this micro-orthographic system, comprising a set of regular correspondences between letter and phoneme components, they should be able to detect that the common part in the written syllables (e.g., “B” in “BA” and “BI”) corresponds to the common part in the phonological syllables (e.g., /b/ in /ba/ and /bi/). The contrast between two different phonological syllables that share the same phoneme in the same syllabic position (especially at the onset, given the abstract nature of consonants) could contribute to the emergence of the common phoneme in participants’ phonological representations. This, in turn, assists participants in extracting that a letter

corresponds to a particular phoneme (i.e., the letter “B” corresponds to the phoneme /b/). We could thus hypothesise that learning regular and effective letters-to-syllable associations might trigger statistical learning, enabling children to detect and extract the regularities of grapheme-phoneme correspondence.

Notably, it is important to strike a balance between the conditions that allow for effective paired-associate learning of regular syllables in a relatively short time (less than two hours in Vazeux et al., 2020) and those that could trigger statistical learning to extract regularities between letters and phonological components. For example, Sargiani et al. (2022) taught their participants 40 syllables during approximately the same learning period as Vazeux et al. and did not obtain the same results as those in Vazeux et al. (2020). This discrepancy may arise because their learning paradigm did not satisfy the first condition, namely laying the robust foundation for paired-associate learning between letter strings and phonological syllables. Learning letter-to-phoneme associations (see Table 3.1(a)) does not satisfy the second condition; that is, within a micro alphabetic system characterized by a one-to-one relationship between letters and phonemes, no regularities exist for extraction.

Connectionist model of reading acquisition (Seidenberg & McClelland, 1989)

The first computational model to ever address statistical learning, accounting for “*the acquisition and use of knowledge concerning orthographic redundancy and orthographic-phonological correspondences*” is the Parallel Distributed Processing (PDP) model (Seidenberg & McClelland, 1989, p. 525).

Contrary to the Dual Route Cascaded (DRC) model (Coltheart et al., 2001), the PDP model posits that a single network facilitates the reading of both irregular words and nonwords. According to the PDP model, reading occurs through a single pathway, facilitated by the

statistical learning of regularities between phonology and orthography, without the application of grapheme-phoneme correspondence rules.

The PDP model is organised into three interconnected layers of code: orthography, phonology, and meaning. These are interconnected through hidden layers, which allow bidirectional inhibitory and excitatory connections.

The initially implemented model was limited to the network between orthography and phonology (see Figure 3.3). The network helps to understand how a child acquires the correspondences between graphemes and phonemes. The model functions as follows: A list of monosyllabic words is randomly selected from a corpus and introduced into the network in triplets of letters. Each triplet of letters first enters at the orthographic level and activates the hidden layers. If there is an error in letter encoding, the hidden layers will send feedback to the orthographic units to correct it. Otherwise, the encoding will be sent to the phonological units through the hidden layers. This results in a proposed phonological representation of the encoding. At this point, the comparison between the network-produced model and the target pronunciation model produces an error score. As syllabic words are presented to the network over time, there are fewer and fewer errors because the model learns the words, whether they are regular or irregular, and consequently, reading becomes quicker and more accurate.

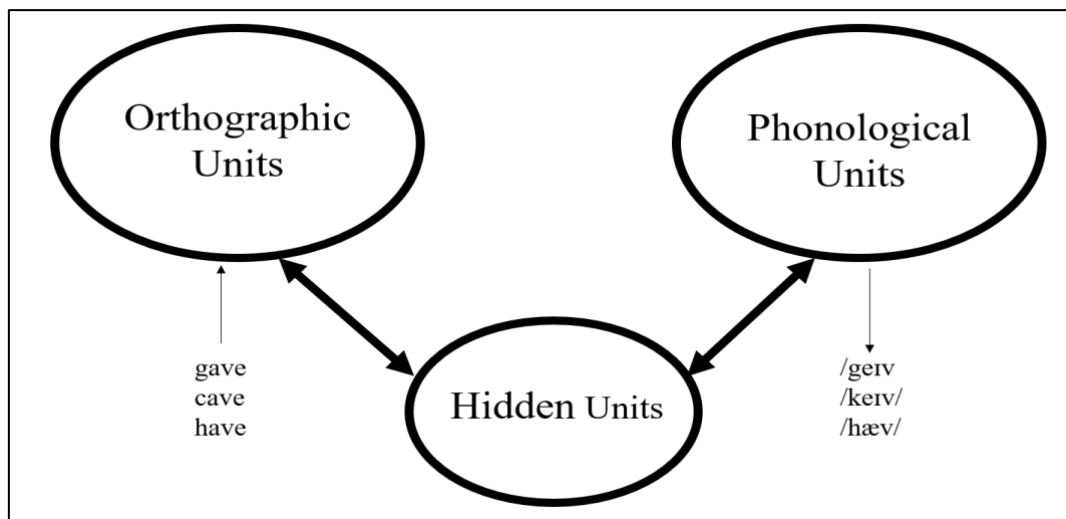
Initially, the weights of the connections are random. The weights are modified each time the network fails to process the orthographic words. Gradually, successive presentations of the same word lead to fewer and fewer changes until the network is stabilised.

Some critics might raise objections regarding the connectionist model of reading acquisition (Seidenberg & McClelland, 1989), specifically noting, at times, the lack of empirical evidence from laboratory experiments to substantiate the claims, let alone their applicability to children learning to read. For instance, it is assumed that the initial model lacks knowledge of reading, and this does not correspond to the reality that a child is already exposed

to spoken language before beginning instruction in reading. In this context, subsequent connectionist models (Harm & Seidenberg, 1999, 2004) consider the influence of initial phonological and semantic knowledge on the ability to learn relationships between orthography and phonology. However, studying these models experimentally still poses difficulties. This thesis serves as a preliminary exploration, initially proposing a theoretical framework inspired by these models, which will subsequently lead to the formulation of research questions and hypotheses.

Figure 3.3

Connectionist model of reading acquisition (Seidenberg & McClelland, 1989)



Towards a theoretical framework: Research questions and hypotheses

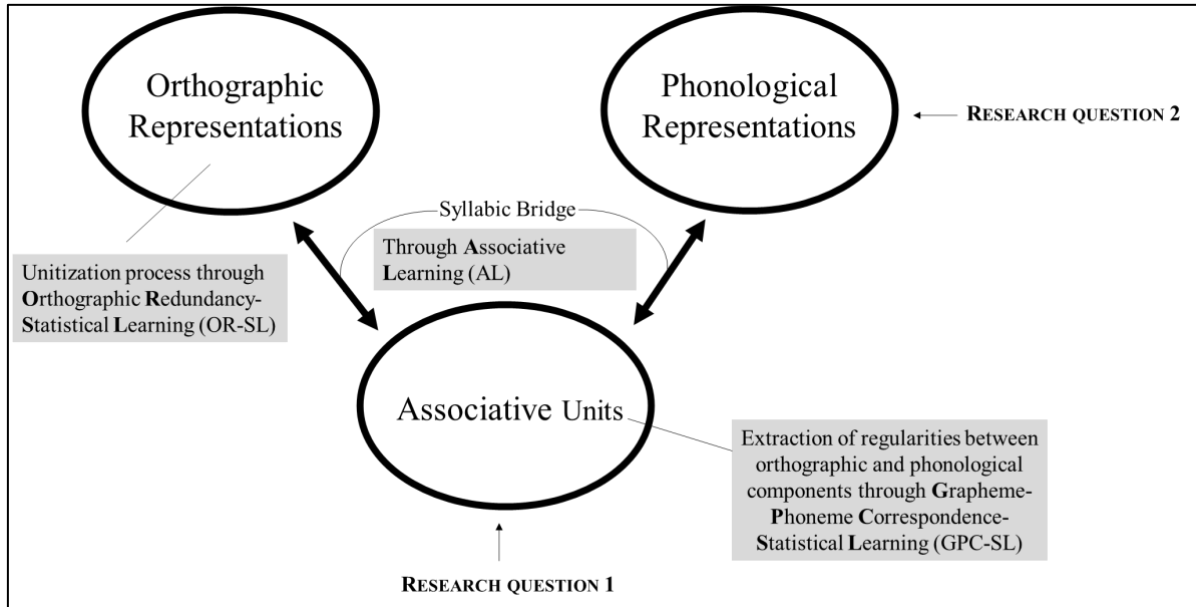
When we sort through the veins discussed above, we discover that they are all logically consistent. Firstly, we posit that the inner structure of writing systems may consist of not only the mappings between written symbols and phonological units, but also the combination of information or cues to guide readers towards the unit of articulation: syllables. This is also the internal logic of the “syllable bridge” hypothesis, suggesting that children start to learn to read by learning the natural units determined by the inner structure of writing units. Meanwhile,

if the inner structure of writing systems is defined by the memorisation of mappings and the combination of information, this implies that it is also possible to extract underlying information from these mappings. The new interpretation of the inner structure of writing systems aligns with the hypothesis that we propose in the current chapter, that the detection and extraction of grapheme-phoneme correspondence regularities might occur through statistical learning (see Chapter 2) in building the *syllabic bridge*.

Overall, what we have described aligns with the connectionist model of word reading proposed by Seidenberg and McClelland (1989). Inspired by this model, we develop a theoretical framework that is illustrated in Figure 3.4. As children start learning to read, they encounter two levels of representation: orthographic and phonological. A noteworthy similarity to the hidden units in Seidenberg and McClelland's connectionist model (1989) is that the orthographic and phonological representations are not directly linked; instead, they are mediated by a set of associative units. At the orthographic level, a *unitisation process* occurs, utilising distributional properties to cluster letters into phonological syllables, as demonstrated in the study by Doignon-Camus and Zagar (2014). The statistical learning mechanism that operates during the unitization process is referred to as *orthographic redundancy-statistical learning* (OR-SL). The processed units at the orthographic level are mapped onto available phonological units through associative units, serving as mediators between the orthographic and phonological representations. This mapping process is achieved through the *associative learning* (AL) mechanism. As learners acquire orthographic-phonological units, another statistical learning mechanism may be invoked. This statistical learning functions to extract grapheme-phoneme correspondence regularities from the correspondences between orthographic and phonological components, referred to as *grapheme-phoneme-correspondence-statistical learning* (GPC-SL).

Figure 3.4

Theoretical framework of learning to read, leading to research questions and hypotheses



Note. OR-SL: Orthographic Redundancy-Statistical Learning; GPC-SL: Grapheme-Phoneme Correspondence-Statistical Learning; AL: Associative Learning.

The *unitisation process* through the OR-SL mechanism occurs at the orthographic representation level. The syllabic bridge is built through the two big arrows (between orthographic representations and associative units, and between phonological representations and associative units) where the AL mechanism is involved. As the syllabic bridge is set up, the GPC-SL mechanism is triggered to extract regularities between orthographic and phonological components at the level of associative units. Adapted from “Before Learning the Code: A Commentary on Sargiani, Ehri, and Maluf (RRQ, 2022)”, by T. Guo, M. Vazeux, N. Doignon-Camus, M-L. Bosse, G. Mahé, and D. Zagar, 2023, *Reading Research Quarterly*, 58(1), p.109. (<https://doi.org/10.1002/rrq.487>). Copyright 2022 by International Literacy Association.

Based on the current theoretical framework, we aim to pose research questions at the levels of associative units and phonological representations, respectively (see Figure 3.4).

Research Question 1:

The first research question, posed at the level of associative units, aims to test the main hypothesis proposed in the current framework: whether statistical learning (specifically GPC-SL), enables prereaders to extract grapheme-phoneme correspondence regularities from an orthographic environment, even prior to explicit phonics instruction. In other words, can learning associations between letter strings and phonological syllables trigger statistical learning and enable children to extract grapheme-phoneme correspondence regularities? (see Chapter 4)

Hypothesis:

We hypothesise that building the *syllabic bridge* might activate statistical learning, potentially allowing the detection and extraction of grapheme-phoneme correspondences in prereaders, even before explicit phonics instruction. If validated, this hypothesis will open up a new perspective on learning to read in the phase before acquiring the alphabetic code.

Research Question 2:

The second research question, while somewhat tangential to reading acquisition, remains highly relevant to the theoretical framework and has the potential to inform our understanding of reading acquisition. Our aim is to explore the nature of the relationship between orthography and phonology during the acquisition of reading. Consequently, the second question is posed at the level of phonological representations (see Figure 3.4). We assess whether participants' responses on a phonological awareness task are influenced by the

interaction between orthographic and phonological representations through associative units. If so, does this influence change as the literacy level evolves? (see Chapter 5)

Hypothesis:

We hypothesise that responses on the phonological awareness task are influenced by statistical orthographic knowledge, which is generated by orthographic-phonological correspondences through the associative units. This influence changes as the literacy level evolves.

CHAPTER 4: ON THE ROLE OF STATISTICAL LEARNING AT THE VERY BEGINNING OF LEARNING TO READ

This chapter reports on two experiments designed to examine how French-speaking children might better generalise grapheme-phoneme correspondence (GPC) regularities through exposure to different micro-orthographic systems consisting of letter-to-syllable associations. The experiments were conducted separately with children from standard kindergartens ($n = 159$) and those from priority education networks ($n = 33$). The procedure was the same for both experiments. The children learned letter-to-syllable associations over 100-minute learning sessions. One set of associations allowed for the extraction of up to eight GPC regularities, referred to as a “rich supply,” while the other set allowed for extracting only up to four GPC regularities, termed a “poor supply.” Pretests and posttests were administered to assess the development of letter knowledge, syllable reading, and phonemic awareness in each condition. In Experiment 4.1, the most significant results were found in a subgroup of children with high letter knowledge but low phonemic awareness at pretests ($n = 67$). Results showed that children trained with the “rich supply” experienced a greater increase in phonemic awareness than those trained with the “poor supply.” In Experiment 4.2, the children trained with the “rich supply” generalised better with syllables that were not explicitly taught during the training programs compared to the “poor supply” group. These findings provide evidence that a set of regular and efficient letter-to-syllable associations might trigger statistical learning, enabling pre-readers to extract GPC regularities.

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EXPERIMENT 4.1

Introduction

Experiment 4.1 is designed to examine the first research question: whether statistical learning enables prereaders to extract grapheme-phoneme correspondence (GPC) regularities from an orthographic environment, more precisely, from a micro set of associations between letter strings and phonological syllables, even prior to explicit phonics instruction. Following the study by Vazeux et al. (2020), we use a final phoneme elision task to assess phonemic awareness, which is taken a preliminary indicator of mastery of the alphabetic principle.

One of the difficulties in designing the experiment is determining how to reveal the involvement of statistical learning in the extraction of GPC regularities. Apfelbaum et al. (2013) highlighted the key role of the orthographic environment in learning GPC regularities through statistical learning. They varied the consonant frames within consonant-vowel-consonant words/syllables that surrounded the GPC regularities for vowels (i.e., the V is CVC syllables) to examine whether it influences the activation of statistical learning in extracting GPC regularities.

We interpreted the results of Vazeux et al. (2020) by hypothesising that learning eight regular letters-to-syllable associations might trigger statistical learning, enabling the detection and extraction of eight GPC regularities, evidenced by improved progress in phonemic awareness. Inspired by the rationale of Apfelbaum et al. (2013), we can provide varying sets of letter-to-syllable associations to examine their influence on the activation of statistical learning, as assessed by phonemic awareness. Consider two orthographic environments with the same number of letter-to-syllable associations, comprising identical letter and phoneme components. If they allow the extraction of varying amounts of GPC regularities, they might induce different levels of statistical learning activation, leading to differing performance in phonemic awareness.

The number of GPC regularities in an orthographic environment is viewed as a kind of “supply” that we can manipulate, and accordingly triggering different activations of statistical learning. In the current study, the same eight letter-to-syllable associations used by Vazeux et al. (2020) were retained. This set is referred to as a “rich supply” (see Table 4.1(a)), as these syllabic associations may allow the extraction of eight regularities; for instance, BA-/ba/ and BI-/bi/ allow the extraction of the regularity that B corresponds to /b/, and FA-/fa/ and FI-/fi/ allow the extraction of the regularity that F corresponds to the sound /f/. With the same letter and phoneme components, different sets of letter-to-syllable associations can be generated, allowing the extraction of varying amounts of GPC regularities, ranging from eight (as in Vazeux et al., 2020) to four GPC regularities (see Appendix B for a thought process with examples). We chose a set of letters-to-syllable associations that could allow the extraction of only four GPC regularities (see Table 4.1(b)). The reason for this is to observe the different activations of statistical learning as clearly as possible. Nevertheless, it is worth noting that the difference between the “rich supply” and the “poor supply” is still subtle; the only variation is the amount of GPC regularities within them: eight vs. four.

Table 4.1

Materials used in the “rich supply” and “poor supply” training groups in Experiment 4.1

(a) “Rich supply”

| Set 1 | A-/a/ | I-/i/ | O-/o/ | U-/y/ | | Set 2 | A-/a/ | I-/i/ | O-/o/ | U-/y/ |
|-------|---------|---------|---------|---------|----|-------|---------|---------|---------|---------|
| B-/b/ | BA-/ba/ | BI-/bi/ | | | or | B-/b/ | | | BO-/bo/ | BU-/by/ |
| F-/f/ | FA-/fa/ | FI-/fi/ | | | | F-/f/ | | | FO-/fo/ | FU-/fy/ |
| T-/t/ | | | TO-/to/ | TU-/ty/ | | T-/t/ | TA-/ta/ | TI-/ti/ | | |
| S-/s/ | | | SO-/so/ | SU-/sy/ | | S-/s/ | SA-/sa/ | SI-/si/ | | |

(b) “Poor supply”

| Set 1 | A-/a/ | I-/i/ | O-/o/ | U-/y/ | | Set 2 | A-/a/ | I-/i/ | O-/o/ | U-/y/ |
|-------|---------|---------|---------|---------|----|-------|---------|---------|---------|---------|
| B-/b/ | BA-/ba/ | BI-/bi/ | BO-/bo/ | BU-/by/ | | B-/b/ | BA-/ba/ | | | |
| F-/f/ | | | FO-/fo/ | FU-/fy/ | or | F-/f/ | FA-/fa/ | | | |
| T-/t/ | | | | TU-/ty/ | | T-/t/ | TA-/ta/ | TI-/ti/ | | |
| S-/s/ | | | | SU-/sy/ | | S-/s/ | SA-/sa/ | SI-/si/ | SO-/so/ | SU-/sy/ |

Note. Both the “rich supply” and “poor supply” materials use a *Latin square* design (set 1 and set 2).

In line with our hypothesis, the “rich supply” may serve as a more effective trigger for statistical learning, thereby resulting in a greater increase in phonemic awareness.

Methods

Design

The study design employed a pretest-learning-posttest paradigm. All participants firstly completed a pretest assessing early literacy skills, including letter knowledge, syllable reading, and phonemic awareness. Participants were preselected based on these initial literacy levels after the pretest (see the “Participants” section for rationale). Eligible students were assigned to either the “rich supply” training group or the “poor supply” training group, with both groups being matched based on their pretest literacy scores. During the learning sessions, both groups received the same tasks but were trained on different syllables: one group with a “rich supply” and the other with a “poor supply.” The posttest was identical to the pretest, but the order of items was changed for each group.

Participants

The participants in the study were preschoolers from Nancy, France ($n = 159$). They were recruited from four public preschools, two of which had medium to high socioeconomic

status and two with low to medium socioeconomic status. All participants had normal vision and hearing and presented no language disorders. All parents or legal guardians of participants provided signed consent forms prior to inclusion in the study. Oral consent forms were obtained from participants.

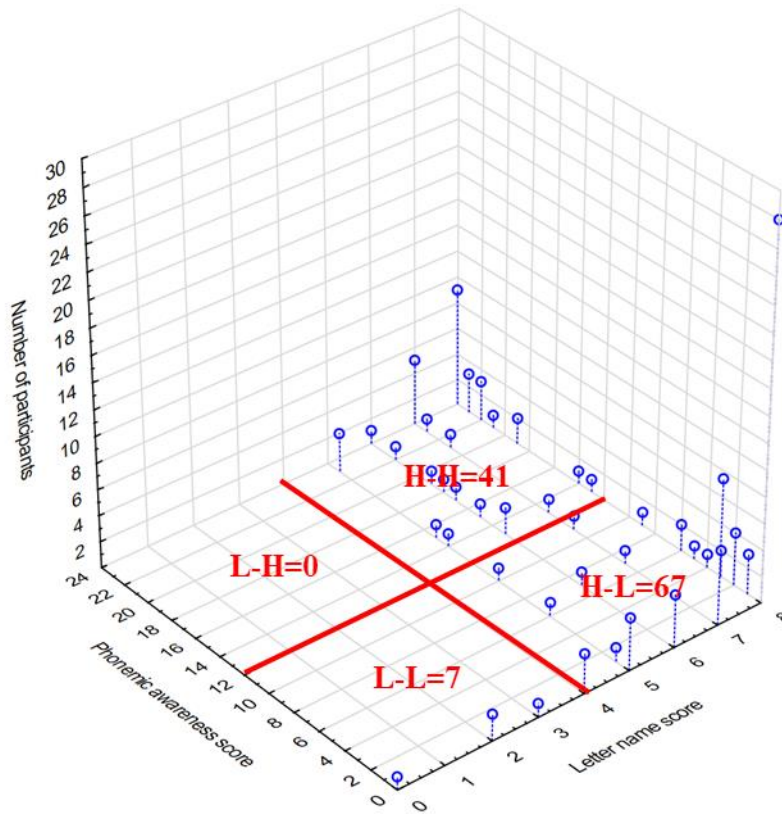
All participants engaged in the pretest, following which a preselection was conducted. Initially, we based our primary selection on the syllable reading task, as the study is designed for prereaders—defined as those unable to read syllables and those not yet exposed to phonics instruction. Consequently, forty-four children who read eight or more syllables out of sixteen in the pretest were excluded from data analysis.

Secondly, we considered the findings by Vazeux et al. (2020), which demonstrated a significantly greater increase in phonemic awareness with the syllable-based approach compared to the phoneme-based approach. This was particularly evident for subgroups with low phonemic awareness and high letter-name knowledge. Guided by this methodology, we selected a similar group by analysing the initial levels of both phonemic awareness and letter-name knowledge. Participants with scores at or above average were classified as having good skills, while those below average were deemed to have poor skills.

As illustrated in Figure 4.1, we divided the cohort of 115 participants into three subgroups based on their pretest scores: a low letter-name knowledge and low phonemic awareness subgroup (L-L, $n = 7$), a high letter-name knowledge and low phonemic awareness subgroup (H-L, $n = 67$), and a high letter-name knowledge and high phonemic awareness subgroup (H-H, $n = 41$). No participants fell into a category of low letter-name knowledge and high phonemic awareness (L-H, $n = 0$). The final sample comprised 67 children from the H-L subgroup. The characteristics of the participants are presented in Table 4.2.

Figure 4.1

Distribution of scores of the three subgroups in the pretest in the letter-name knowledge and phonemic awareness tasks in Experiment 4.1



Note. L-L = low letter name knowledge/low phonemic awareness. L-H = low letter name knowledge /high phonemic awareness. H-H = high letter name knowledge/high letter name knowledge.

Table 4.2

Characteristics of participants in Experiment 4.1

| Characteristics | “Rich Supply” | “Poor Supply” |
|----------------------------|---------------|---------------|
| <i>N</i> | 34 | 33 |
| <i>Latin square design</i> | | |
| Set 1 | 15 | 15 |

| | | |
|---------------------|------------|------------|
| Set 2 | 19 | 18 |
| Gender | | |
| Boys | 15 | 16 |
| Girls | 19 | 17 |
| Lateralization | | |
| Right-handed | 27 | 24 |
| Left-handed | 7 | 9 |
| Age | | |
| <i>M</i> years (SD) | 5.50(0.33) | 5.62(0.34) |

Note. N, number of participants; M, mean; SD, standard deviation.

Procedure and materials

The study was conducted in the last year of preschool during school hours. Children were tested individually during the pretest, which lasted approximately 15 minutes. After the pretest, eligible children were equally divided into two groups: the “rich supply” group and the “poor supply” group. They were further equally divided into Set 1 or Set 2 to eliminate syllable material effects. Children in both groups were taken from class in small groups of 2-3 to participate in four 15- to 25-minute sessions, during which they were taught eight syllables. The posttest, identical to the pretest, was administered the day following the learning sessions. The procedure and the materials of the pretest, learning sessions, and posttest were presented as follows.

Pretest

The tasks at the pretest were administrated in the following order (see Appendix C for a sample of the test form).

Letter knowledge. We used eight target letters that composed consonant-vowel (CV) syllables during the learning sessions (i.e., “A”, “I”, “O”, “U”, “B”, “T”, “F”, and “S”). The

children were shown these written letters, with each printed on a 10 x 10 cm white cardboard sheet in uppercase Calibri 72 font. They were asked to name all eight letters and to say the sounds of the consonants aloud. No feedback and no stop rule were given when children failed. Correct responses were noted and scored.

Syllable reading. We used 16 CV syllables composed of 8 target letters (i.e., “BA”, “BI”, “BO”, “BU”, “TA”, “TI”, “TO”, “TU”, “FA”, “FI”, “FO”, “FU”, “SA”, “SI”, “SO”, and “SU”). The children were shown these written syllables, with each syllable printed on a 10 x 10 cm white cardboard sheet in uppercase in uppercase Calibri 72 font. They were asked to read them. No feedback and no stop rule were given.

Final phoneme elision. The final phoneme elision task used consonant-vowel-consonant (CVC) syllables. The stimulus syllables were recorded by a native French-speaking female who majored in speech therapy. They were played through an external stereo connected to a computer running E-Prime 2.0 software (Version 2.0; Schneider et al., 2012). The computer was operated by the examiner. The children were asked to remove the final sound of the stimulus syllable and then say the target syllable (e.g., /bak/-/ba/). Before starting the test, they were given one example and two trials with feedback. No feedback was provided during the test itself. Among 24 CVC syllables, eight were made by syllables to be learned in the learning sessions (see Table 4.1), eight were made by syllables not included in the participants’ learned set but that were composed of the target letters, and eight were made by new syllables composed of new consonants that had not been learned in the program, such as “V” /v/, “P” /p/, “M” /m/, “R” /r/ (e.g., “VIP” /vip/, “MUL” /myl/). A stopping rule was applied after four incorrect items for learned syllables and after two incorrect items for unlearned syllables and new syllables.

Learning sessions

During four learning sessions, children learned eight correspondences between written and spoken syllables with one instructor and one assistant instructor. In each of the first two sessions,

children learned four new syllables. In each of the subsequent two sessions, children reviewed four learned syllables. Children were always corrected when an uncorrected response was given. A variety of tasks were used, and they are described in Table 4.3. All the syllables and pictures used during the learning sessions were presented in a booklet bound in A4 paper, with the syllables printed in uppercase Calibri 72 font.

Table 4.3

Descriptions of the tasks during the learning sessions

| Tasks | Description |
|-----------------------|--|
| Syllable introduction | The instructor displayed a picture (e.g., a picture of a ship) and asked the children to name the picture (in this case, “ship”, in French, is “bateau” /bato/). Then, the children were asked to find the first syllable and say it aloud (e.g., /ba/ from /bato/). |
| Syllable reading | First, the children were shown four syllables and repeated them aloud with the instructor. Next, the syllables were rearranged, and the children were asked to read them aloud again, this time without the instructor’s help. Finally, after another rearrangement of the syllables, the instructor asked the children to read them individually. |
| Die exercise | The children took turns rolling a six-sided die, four sides of which had syllables written on them. The children were asked to read the syllable aloud that was written on the upper side of the rolled die. When they provided the correct response, they advanced their pawn on a 3-square board. |
| Lotto exercise | The children were given a lotto grid with four written syllables; they had to listen to the sound of the syllable pronounced by the instructor and locate the corresponding written syllable on the lotto grid. |
| Relay exercise | Two children played together: the first child was asked to read a written syllable aloud; the second child was asked to listen and memorise the phonological syllable just heard, then cross the classroom, and, from a set of four written syllables, locate the matching syllable and confirm it with the first child; they then switched roles. |
| Syllable review | Children were asked to read all eight learned syllables individually. |

Posttest

The posttest is composed of the same tasks as the pretest, with only the order of items differing between the two training groups. The order of items in the letter knowledge remained unchanged. In the syllable reading task, the learned syllables were firstly presented, which were those have been taught to the children during learning sessions, followed by the unlearned syllables, which were those were not taught during learning sessions but were composed of the target letters. In the phonemic awareness task, Block 1 and Block 2 used CVC syllables composed of corresponding learned and non-learned syllables from the syllable reading task. The order of the CVC syllables in each block remained unchanged.

Data analysis

Our research question was to examine how the Training Group variable affected development of literacy skills, especially phonemic awareness. The analysis of both pretest and posttest data were analysed using a Generalised Linear Mixed Model (GLMM) with the lme4 package (Bates et al., 2015) in R (version 4.2.3; R Core Team, 2023). The GLMM incorporated a fixed effect for the Test factor (pretest vs. posttest, within-participant), a fixed effect for the Training Group factor (“Rich Supply” vs. “Poor Supply”, between-participants), by-participant random intercepts and slopes, and by-item random intercepts.

We chose the pretest as the reference level for the Test factor and the suboptimal as the reference level for the Training Group factor. This allowed us to investigate the simple effects of Test, Training Group, and their interaction effect. The dependent variables (i.e., letter knowledge, syllable reading, and phonemic awareness) were binary (1 = correct and 0 = incorrect), indicating the accuracy of each trial. Consequently, the model was a logistic regression. In the phonemic awareness task, the stopping rule was applied after four consecutive incorrect items for learned syllables and after two consecutive incorrect items for unlearned

syllables and new syllables. This rule was based on the assumption that the participant was not able to produce correct responses. Therefore, items that received no response were interpreted as incorrect responses, attributed to the participants' inability rather than randomly missing data.

Results

Letter Knowledge

There was a significant effect of Test on letter naming ($\beta = 1.17$, $SE = 0.44$, $Z = 2.68$, $p < .01$). This result points to a notable improvement in letter naming (see Table 4.4). The effect of Training Group was not significant ($\beta = 0.32$, $SE = 0.54$, $Z = 0.59$, $p = 0.55$), indicating that the type of training group did not meaningfully affect letter naming. Furthermore, there was no significant interaction between Test and Training Group ($\beta = -0.10$, $SE = 0.64$, $Z = -0.16$, $p = 0.88$). This result suggests that the improvement in letter naming from the pretest to the posttest did not differ significantly between the “rich supply” and “poor supply” groups.

There was a significant effect of Test on consonant letter sounding ($\beta = 2.12$, $SE = 0.50$, $Z = 4.31$, $p < .0001$). This result points to a notable improvement in consonant letter sounding (see Table 4.4). The effect of Training Group was not significant ($\beta = -0.14$, $SE = 0.98$, $Z = -0.15$, $p = 0.88$), indicating that the type of training group did not meaningfully affect letter name knowledge. Furthermore, there was no significant interaction between Test and Training Group ($\beta = 0.18$, $SE = 0.67$, $Z = 0.27$, $p = 0.79$). This result suggests that the improvement in consonant letter sounding from the pretest to the posttest did not differ significantly between the “rich supply” and “poor supply” groups.

Syllable Reading

There was a significant effect of Test on syllable reading ($\beta = 4.78$, $SE = 0.49$, $Z = 9.66$, $p < .0001$). This result points to a notable improvement in syllable reading from the pretest to

the posttest (see Table 4.4). The effect of Training Group was not significant ($\beta = 0.61$, $SE = 0.65$, $Z = 0.95$, $p = 0.34$), indicating that the type of training group did not meaningfully affect syllable reading. Furthermore, there was no significant interaction between Test and Training Group ($\beta = 0.03$, $SE = 0.61$, $Z = 0.04$, $p = 0.97$). This result suggests that the improvement in syllable reading from the pretest to the posttest did not differ significantly between the “rich supply” and poor “supply groups”. However, a marginal superiority was noted in the syllable reading improvement of the “rich supply” group (pretest: 1.8%; posttest: 52.0% accuracy) compared to the “poor supply” group (pretest: 1.0%; posttest: 38.6% accuracy).

Upon conducting a more detailed analysis, we observed a significant effect of Test on learned syllable reading ($\beta = 8.40$, $SE = 1.24$, $Z = 6.79$, $p < .0001$). This result, which aligns with our expectations, indicates that the training program employed in the current study effectively facilitated syllable reading in children. However, there was no significant effect of Training Group ($\beta = 1.63$, $SE = 1.31$, $Z = 1.24$, $p = 0.21$) and no significant interaction between Training Group and Test ($\beta = -0.35$, $SE = 1.32$, $Z = -0.27$, $p = 0.79$).

As for nonlearned syllable reading, the analysis revealed a significant effect of the Test variable ($\beta = 3.15$, $SE = 0.70$, $Z = 4.49$, $p < .0001$). This indicated a significant improvement in nonlearned syllable reading. However, we did not observe any significant effects of the Training Group variable ($\beta = 0.43$, $SE = 1.39$, $Z = 0.31$, $p = 0.76$) or the interaction between Training Group and Test ($\beta = 1.73$, $SE = 1.04$, $Z = 1.66$, $p = 0.10$).

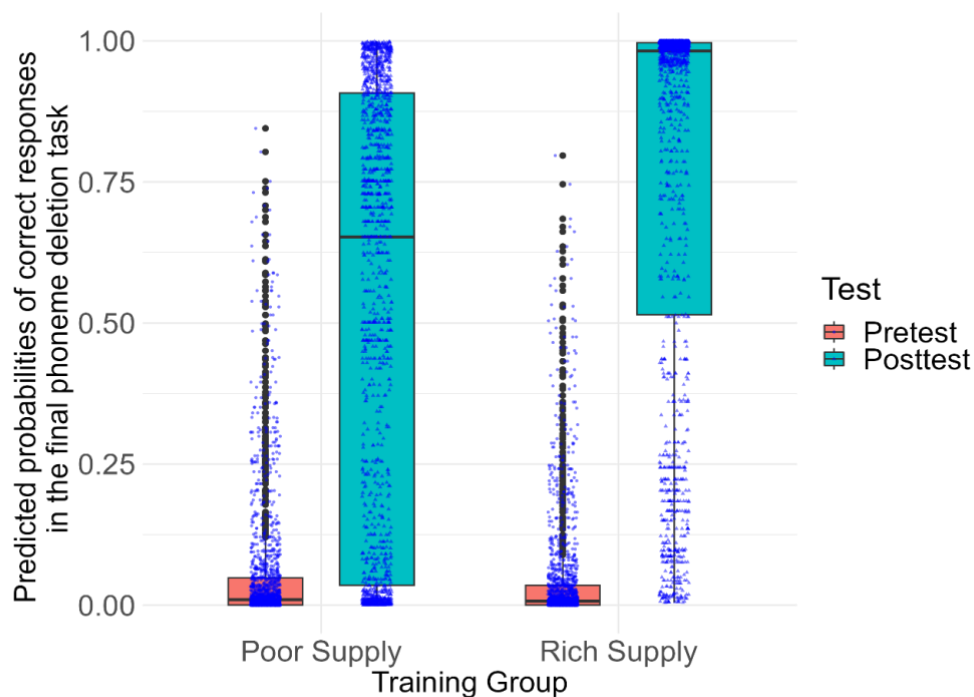
Phonemic Awareness

There was a significant effect of Test on phonemic awareness scores ($\beta = 5.26$, $SE = 0.31$, $Z = 16.94$, $p < .0001$), indicating a substantial improvement from the pretest to the posttest. There was no effect of Training Group ($\beta = -0.33$, $SE = 1.02$, $Z = -0.32$, $p = 0.75$). However, a significant interaction was found between Test and Training Group ($\beta = 3.70$, $SE = 0.63$, $Z =$

5.83, $p < .0001$) (see Figure 4.2). This result aligns with our primary hypothesis that the “rich supply” training group would show greater improvement in phonemic awareness compared to the “poor supply” training.

Figure 4.2

Boxplot presenting the proportion of correct responses in the phonemic awareness task by group and by test conditions in Experiment 4.1



The phonemic awareness task consisted of three blocks: block 1 comprised eight CVC syllables with CV learned syllables, block 2 comprised eight CVC syllables with CV non-learned syllables, and block 3 comprised eight CVC syllables with other syllable. Given this design, we conducted a comprehensive analysis to examine whether consistent effects are observed across all blocks. For the block 1 and block 2, consistent with the general interaction model, there were a significant Test effect and a significant interaction between Test and Training Group, while there was no Training Group effect (see Table 4.5). For Block 3, there

was a significant Test effect and a significant interaction between Test and Training Group. Unexpectedly, the Group effect was also found to be significant (see Table 4.5).

Table 4.4

Percentage of correct responses in preliteracy assessments by group and test conditions in Experiment 4.1

| Training group | Test | Letter name | Letter sound | Learned syllable | Nonlearned syllable | Phonemic awareness |
|----------------|-----------|-------------|--------------|------------------|---------------------|--------------------|
| “Rich supply” | Pretests | 93.0% | 14.7% | 2.2% | 1.5% | 5.4% |
| | Posttests | 97.1% | 33.8% | 79.8% | 24.3% | 74.6% |
| “Poor supply” | Pretests | 91.3% | 15.2% | 0.4% | 1.5% | 5.7% |
| | Posttests | 96.6% | 32.6% | 66.7% | 10.6% | 51.0% |

Table 4.5

Main effects and interaction effects across the three blocks in the phonemic awareness task in Experiment 4.1

| | Learned syllables | | | | Nonlearned syllables | | | | Other syllables | | | |
|------------|-------------------|------|-------|--------|----------------------|------|-------|--------|-----------------|------|------|--------|
| | β | SE | Z | p | β | SE | Z | p | β | SE | Z | p |
| Test | 4.57 | 0.45 | 10.17 | <.0001 | 7.72 | 0.93 | 8.30 | <.0001 | 13.94 | 2.28 | 6.10 | <.0001 |
| Group | -0.50 | 0.98 | -0.51 | 0.61 | -0.33 | 1.97 | -0.17 | 0.87 | 10.74 | 3.71 | 2.89 | <.01 |
| Test*Group | 4.10 | 0.96 | 4.26 | <.0001 | 8.71 | 2.23 | 3.90 | <.0001 | 8.29 | 3.50 | 2.37 | <.05 |

Note. β , coefficient; SE, Standard Error; Z, Z-score; p, p-value.

Discussion

The primary aim of Experiment 5.1 was to whether statistical learning might be triggered to detect and extract GPC regularities from a micro-orthographic environment. To do

so, the participants learned eight letters-to-syllable associations embedded with either eight (i.e., “rich supply”) or four GPC regularities (i.e., “poor supply”).

We observed an improvement of letter knowledge, syllable reading in both training groups, but there was no significant difference between two training groups. Importantly, we found that the “rich supply” training group exhibited a significant greater increase in phonemic awareness compared to the “poor supply” training group. Our findings showed that the “rich supply” might induce a stronger activity of statistical learning, consequently leading to a better implicit understanding of GPC regularities, compared to the poor supply.

How does the generalisation of GPC regularities through statistical learning occur? Apfelbaum et al. (2013) was the only study exploring the possibility of extracting GPC regularities from an orthographic environment. They showed that variability in consonant frames (within CVC syllables) surrounding vowel GPC regularities helps children acquire invariant GPC regularities. They account for the results by arguing that when consonant frames are variable and irrelevant, children would not make efforts to form associations with them. Instead, variability in irrelevant elements helps children focus on the essential - the vowel GPC regularities surrounded by these variable consonant frames.

As for the “rich supply” in the current study, the orthographic environment, consisting of eight regular letters-to-syllable associations, is much more simplified compared to that of Apfelbaum et al. (2013). One prerequisite for triggering statistical learning is that these associations between letter strings and phonological units are solidly established. Children were explicitly taught these eight associations during four 25-minute learning sessions, and they could be able to pay attention to both elements of them and make statistics. The “rich supply” allows them to make statistics of eight GPC regularities, naturally enabling them to improve phonemic awareness better than the “poor supply,” which allows them to make statistics of eight GPC regularities.

At a larger level, this work also reveals some underlying mechanisms about the nature of early literacy acquisition. It is highly likely that early literacy acquisition involves both explicit learning and statistical learning working in tandem (Sun et al., 2005). For example: the fact that the “rich supply,” results in superior performance in phonemic awareness, compared to the “poor supply” that suggests something more than just memorising the set of eight syllables is happening; it is as if the brain reorganises the learned orthographic environment. The hypothesis we are proposing is that from the set of eight written-oral syllabic associations (e.g., BA-/ba/, BI-/bi/, etc.), the brain reorganises the associations based on the extraction of regularities (e.g., B-/b/, A-/a/, I-/i/, etc.). We hypothesise that this reorganisation is carried out by the statistical learning mechanism. In what form is this information stored? This is a question worth exploring further:

Learning to read thus involves both cross-modal associative learning and statistical learning mechanisms. Our findings suggest that it is possible to detect and extract regularities through statistical learning from associative learning of letters-to-syllable pairs. We can hypothesize that the quality of the extraction of regularities through statistical learning might depend on whether the associations between orthography and phonology are well-established through associative learning. The present study introduces the initial concept with which to investigate the interplay between statistical learning and cross-modal associative learning.

At the larger level, this work also reveals some underlying mechanisms about the nature of the early literacy acquisition. It is highly likely that early involves both explicit and implicit statistical learning working in tandem (Sun et al., 2005). However, it remains unclear what should be conveyed explicitly and what should be assimilated implicitly. Our findings provide a conception of the cooperation of explicit and implicit statistical learning processes. The information that is provided explicitly can be elucidated to children in an easy-to-understand way. Our study provided letters-to-syllable associations that can be both clearly explained to children and easily grasped by

them. Learning to read thus involves both a cross-modal associative learning and a statistical learning mechanism. Our findings suggest that it is possible to detect and extract regularities through statistical learning from an associative learning. We can hypothesize that whether the quality of the extraction of regularities through statistical learning might depend on whether the associations are well established between orthography and phonology through an associative learning. The present study introduces a platform with which to investigate the interplay between statistical learning and cross-modal associative learning.

Moreover, individual differences in statistical learning abilities have been broadly explored (Bogaerts et al., 2022; Torkildson et al., 2019; Siegelman, Bogaerts, & Frost, 2017; Siegelman, Bogaerts, Christiansen et al., 2017; Siegelman et al., 2022; Segelman et al., 2020; Witteloostuijn et al., 2021). This indicates that the capacity to detect and extract regularities from orthographic-phonological associative learning varies, contributing differently to the acquisition of reading skills. Our findings also suggest that, instead of allowing children to discover regularities from a randomly structured orthographic environment, driven by their individual statistical learning capacity, we can carefully manipulate the orthographic environment to potentially enhance the activation of statistical learning. This could be a future research direction, focusing on studying various orthographic environments to enhance the implicit acquisition of reading skills.

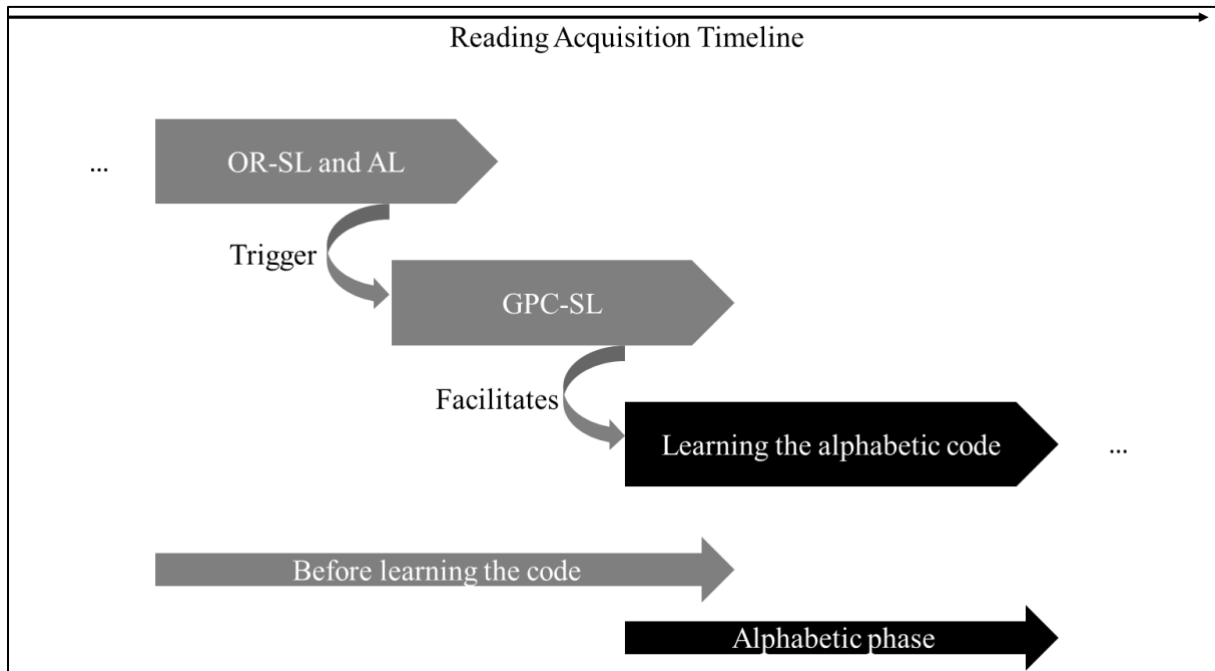
The current experimental paradigm also provides a new conception of how to experimentally explore the connectionist model of word reading (Seidenberg & McClelland, 1989), which accounts for the extraction of GPC regularities from orthographic-phonological correspondences. Previous studies have paid particular attention to including all kinds of unimodal underlying regularities in a statistical learning task to which participants are exposed (as reviewed in Chapter 2). While some studies have presented cross-modal orthographic-phonological associations through specific computer tasks (e.g., Apfelbaum et al., 2013; He &

Tong, 2017), statistical learning can also occur when we explicitly teach associations between orthography and phonology. The process of memorising cross-modal visual-verbal pairs through explicit associative learning is not contradictory to the simultaneous involvement of statistical learning. Future studies on statistical learning can thus consider using an explicit learning task, which permits children to establish solid orthographic-phonological associations.

As a practical level, our findings provide implications about how to learn to read. The perspectives of providing a small set of regular and efficient letters-to-syllable associations to trigger statistical learning, enabling the extraction of GPC regularities at the very beginning of learning to read, does not imply to replace any explicit phonics instructions; it is all about timing and sequencing. If we place the process of learning to read on a reading acquisition timeline, we can distinguish a phase before learning the alphabetic code, and a phase of learning the alphabetic code (see Figure 4.3). During the phase before learning the alphabetic code, the perspective in the present study provides an alternative approach for prereaders, especially for those who struggle to assimilate the abstract phonemic units, which are considered a literate cognitive concept (Morais, 2021). This process in which statistical learning and associative learning are involved could not only act as a booster for future literacy acquisition, but also a viable option for children facing challenge with statistical learning abilities. The phase before learning the code can be seen as a kind of warm-up exercise. Once prereaders are well-prepared, it becomes an appropriate moment to introduce phonics instruction. Future research is needed to investigate the timing question. As prereaders progress towards a comprehensive understanding of the alphabetic code, it can be linked to the study of Apfelbaum et al. (2013) and Roembke et al. (2020), which concerned the orthographic environment that should be provided in learning more complex GPC regularities.

Figure 4.3

Schematisation of the early literacy acquisition timeline



Note. This figure demonstrates the reading acquisition timeline. Three cognitive mechanisms are involved before learning the code (OR-SL: orthographic redundancy statistical learning; AL: Associative learning; GPC-SL: grapheme-phoneme-correspondence statistical learning). From “Before Learning the Code: A Commentary on Sargiani, Ehri, and Maluf (RRQ, 2022)”, by T. Guo, M. Vazeux, N. Doignon-Camus, M-L. Bosse, G. Mahé, and D. Zagar, 2023, *Reading Research Quarterly*, 58(1), p.109. (<https://doi.org/10.1002/rrq.487>). Copyright 2022 by International Literacy Association.

The current perspective opens up new direction for future study. Our perspective suggests that learning to read can start by associative learning between letter strings and phonological syllables. A key question is when associative learning should occur. It has been found that Korean children read more than half their syllables by the age of three (Cho, 2009; Cho & McBride-Chang, 2005). The precocity of reading acquisition in Korean Hangul would

find an explanation in the fact that letters composing a syllable are clearly defined into perceptual units; then, building the syllabic bridge would only involve pairing a printed syllable with its pronounceable sound. This learning is also probably feasible at a very early stage of learning to read in children who learn a linear alphabetic writing system. Further research is needed to determine this period in the reading acquisition timeline (see Figure 4.3).

Secondly, if letters-to-syllable associative learning can trigger statistical learning, the key question concerns the type and number of syllabic associations needed to be learned to efficiently trigger statistical learning. The types of syllables can be defined in terms of variability. Apfelbaum et al. (2013) showed that variability in irrelevant consonants could help first graders acquire GPC regularities for vowels. A subsequent study by Roembke et al. (2020) further examined how consonant variability affects the acquisition of regularities for vowels with high overlap (e.g., EA, AI) or low overlap (e.g., EE, AI). However, their findings did not demonstrate a beneficial effect of consonant variability. It is worth noting that these studies highlighted the variability of irrelevant consonants—not the GPC regularities themselves—in children who might already be instructed in some GPC rules at school. However, our findings suggest the possibility of extracting GPC regularities even before children are explicitly instructed in any rules. Thus, when future studies explore how to leverage the orthographic environment to optimize statistical learning, it is important to consider the learning phase in which the children are situated.

Once statistical learning is setup to help students understand the alphabetic principle, the optimal moment of intervention for decoding instructions must be determined. This question and the other above-listed questions pertain to an intriguing topic about cognitive measures that can be used to track the progress of learning regularities through statistical learning. Previous research commonly employed statistical learning tasks to measure the general capacity of statistical learning, such as artificial grammar learning, serial reaction time, and statistical

learning embedded-pattern tasks (for a review, see Bogaerts et al., 2021). These tasks may not be suitable for the measurement of the ability of extraction of well-defined grapheme-phoneme correspondence regularities. The study by Vazeux et al. (2020) and the current study used phonemic awareness to capture the first signs of the mastery of the alphabetic code, which may be a good indicator of the progress in extracting regularities. However, a limitation arises in that phonemic awareness does not directly assess the generalisation of the GPC regularities. Directly observing progress in learning GPC regularities is especially challenging, given that prereaders possess only a very low literacy level, that is, they have only some letter knowledge and a low level of phonemic awareness. This limitation will be specifically considered in Experiment 4.2.

EXPERIMENT 4.2

Introduction

Experiment 4.2 was originally designed to examine whether statistical learning could be triggered to extract GPC regularities in children at risk for reading disability, thereby assisting them in catching up with the literacy level of their normally developing peers. Consequently, the study was conducted among French-speaking children within priority education networks in France.

In France, the priority education policy aims to counteract the impact of social and economic inequalities on educational achievement. This is achieved by intensifying teaching and educational efforts in schools and institutions located in regions confronting notable social challenges. According to the Department of Evaluation, Forecasting, and Performance, nine out of ten middle schools in priority education networks accommodate more than 60% of students from socially disadvantaged backgrounds. The students in these middle schools tend to be academically fragile.

Concerning reading aspects, reading difficulties can be observed from the first grade in primary school through to adulthood, especially during middle school years. It appears that the affirmed difficulties upon entering middle school stem from challenges encountered during the initial stages of learning to read. Therefore, it is crucial to identify children at risk for reading difficulties and to intervene as early as possible.

In the current study, participants from two schools within priority education networks demonstrated a literacy level comparable to children from standard schools. Due to their intensive training in phonemic awareness, all participants performed well on the final phoneme elision task. These participants cannot be considered at risk for reading disability at the time of participating in the experiment. While they might be at risk for reading disability in the long term, the literacy assessments used do not allow us to draw this conclusion. However, since

participants started with a high level of phonemic awareness, this experiment provides an opportunity to measure the effects of statistical learning at a more advanced level of literacy preparation. As a result, we cannot observe a significant impact on phonemic awareness due to the initially high level; however, we might observe an effect on more advanced skills, such as the generalisation of untaught syllable reading. For instance, according to the hypothesis, if the “rich supply” allows the extraction of eight GPC regularities, it might enable children to generalise nonlearned syllables readable by the extracted eight GPC regularities (i.e., the green parts in Table 4.6(a)). Conversely, the GPC regularities extracted from the “poor supply” would not allow children to read the nonlearned syllables (i.e., the red parts in Table 4.6(b)). As a result, we can hypothesize that children trained with the “rich supply” would read better nonlearned syllables than those trained with the “poor supply.”

Experiment 4.2 follows Experiment 4.1 in continuity. Experiment 4.1 demonstrated that the “rich supply” led to better progress in phonemic awareness than the “poor supply.” One might argue that this is not a direct demonstration of the extraction of GPC regularities. The current study might allow us to observe the direct extraction of the GPC regularities by monitoring progress on nonlearned syllables.

Table 4.6

Materials used in the “rich supply” and “poor supply” training groups in Experiment 4.2

(a) “Rich supply”

| Set 1 | A-/a/ | I-/i/ | O-/o/ | U-/y/ | | Set 2 | A-/a/ | I-/i/ | O-/o/ | U-/y/ |
|-------|---------|---------|---------|---------|-------|---------|---------|-------|---------|---------|
| B-/b/ | BA-/ba/ | BI-/bi/ | | | or | B-/b/ | | | BO-/bo/ | BU-/by/ |
| F-/f/ | FA-/fa/ | FI-/fi/ | | | | F-/f/ | | | FO-/fo/ | FU-/fy/ |
| T-/t/ | | | TO-/to/ | TU-/ty/ | T-/t/ | TA-/ta/ | TI-/ti/ | | | |
| S-/s/ | | | SO-/so/ | SU-/sy/ | S-/s/ | SA-/sa/ | SI-/si/ | | | |

(b) “Poor supply”

| Set 1 | A-/a/ | I-/i/ | O-/o/ | U-/y/ | | Set 2 | A-/a/ | I-/i/ | O-/o/ | U-/y/ |
|-------|---------|---------|---------|---------|----|-------|---------|---------|---------|---------|
| B-/b/ | BA-/ba/ | BI-/bi/ | BO-/bo/ | BU-/by/ | | B-/b/ | BA-/ba/ | | | |
| F-/f/ | | | FO-/fo/ | FU-/fy/ | or | F-/f/ | FA-/fa/ | | | |
| T-/t/ | | | | TU-/ty/ | | T-/t/ | TA-/ta/ | TI-/ti/ | | |
| S-/s/ | | | | SU-/sy/ | | S-/s/ | SA-/sa/ | SI-/si/ | SO-/so/ | SU-/sy/ |

Note. Both the “rich supply” and “poor supply” materials use a Latin square design (set 1 and set 2). The green and red parts represent the nonlearned syllables in the “rich supply” and “poor supply,” respectively.

Methods

Experiment 4.2 utilized the same design, procedure, and materials as Experiment 4.1, and these are not presented again in Experiment 4.2.

Participants

The participants in the study were preschoolers from two preschools in priority education networks in Maxéville, France ($n = 43$). All participants had normal vision and hearing and presented no language disorders. All parents or legal guardians of participants provided a signed consent form prior to inclusion in the study. Oral consent was obtained from participants.

The same preselection was conducted using the same criterion as in Experiment 5.1. According to the pretest, seven children who read eight or more syllables out of sixteen were considered overqualified for the present study and were not selected. The 36 eligible students were assigned to either the “rich supply” training group or the “poor supply” training group, with both groups being matched based on their pretest literacy scores. During the learning

sessions and posttest, three children could not complete the experiment due to absence. The final sample comprised 33 children ($M_{age} = 6$ years old; 19 boys and 14 girls).

Data Analysis

The research question was to examine how the Training Group variable affected development of literacy skills, especially nonlearned syllable reading. As in Experiment 5.1, the analysis of both pretest and posttest data were analysed using a Generalised Linear Mixed Model (GLMM) with the lme4 package (Bates et al., 2015) in R (version 4.2.3; R Core Team, 2023). The GLMM incorporated a fixed effect for the Test factor (pretest vs. posttest, within-participant), a fixed effect for the Training Group factor (“Rich Supply” vs. “Poor Supply”, between-participants), by-participant random intercepts and slopes, and by-item random intercepts. We chose the pretest as the reference level for the Test factor and the suboptimal as the reference level for the Training Group factor. This allowed us to investigate the simple effects of Test, Training Group, and their interaction effect. The dependent variables (i.e., letter knowledge, syllable reading, and phonemic awareness) were binary (1 = correct and 0 = incorrect), indicating the accuracy of each trial. Consequently, the model was a logistic regression.

Results

Letter Knowledge

The participants had reached the ceiling in the letter name knowledge task at the pretest, with a proportion of correct responses of 91.9% in the “rich supply” training group and 94.1% in the “poor supply” training group (see Table 4.7). Not surprisingly, there were no significant effects of Test ($\beta = 0.69$, $SE = 0.67$, $Z = 1.03$, $p = 0.30$), Training Group ($\beta = -0.52$, $SE = 1.15$, $Z = -0.45$, $p = 0.95$), or interaction between them ($\beta = -0.20$, $SE = 0.88$, $Z = -0.23$, $p = 0.82$).

Regarding the consonant letter sounding task, minor progress was observed in both the “rich supply” training group (pretest: 39.7%, posttest: 50%) and “poor supply” (pretest: 41.7%, posttest: 48.4%). However, there were no significant effects of Test ($\beta = 0.78$, $SE = 0.51$, $Z = 1.53$, $p = 0.13$), Training Group ($\beta = 0.24$, $SE = 1.09$, $Z = 0.22$, $p = 0.82$), or interaction between them ($\beta = 0.06$, $SE = 0.69$, $Z = 0.08$, $p = 0.93$).

Syllable Reading

There was a significant effect of Test on syllable reading ($\beta = 4.88$, $SE = 0.63$, $Z = 7.71$, $p < .0001$), pointing to a notable improvement in syllable reading from the pretest to the posttest (see Table 4.7). The effect of Training Group was not significant ($\beta = 0.20$, $SE = 1.05$, $Z = 0.18$, $p = 0.88$), indicating that the type of training group did not meaningfully affect syllable reading. Furthermore, there was no significant interaction between Test and Training Group ($\beta = 1.40$, $SE = 0.89$, $Z = 1.58$, $p = 0.12$). This result suggests that the improvement in syllable reading from the pretest to the posttest did not differ significantly between the “rich supply” and “poor supply” groups. However, despite an insignificant interaction effect, better progress on syllable reading was observed in the “rich supply” training group compared to the “poor supply” training group (pretest: 2.1%, posttest: 38.3%).

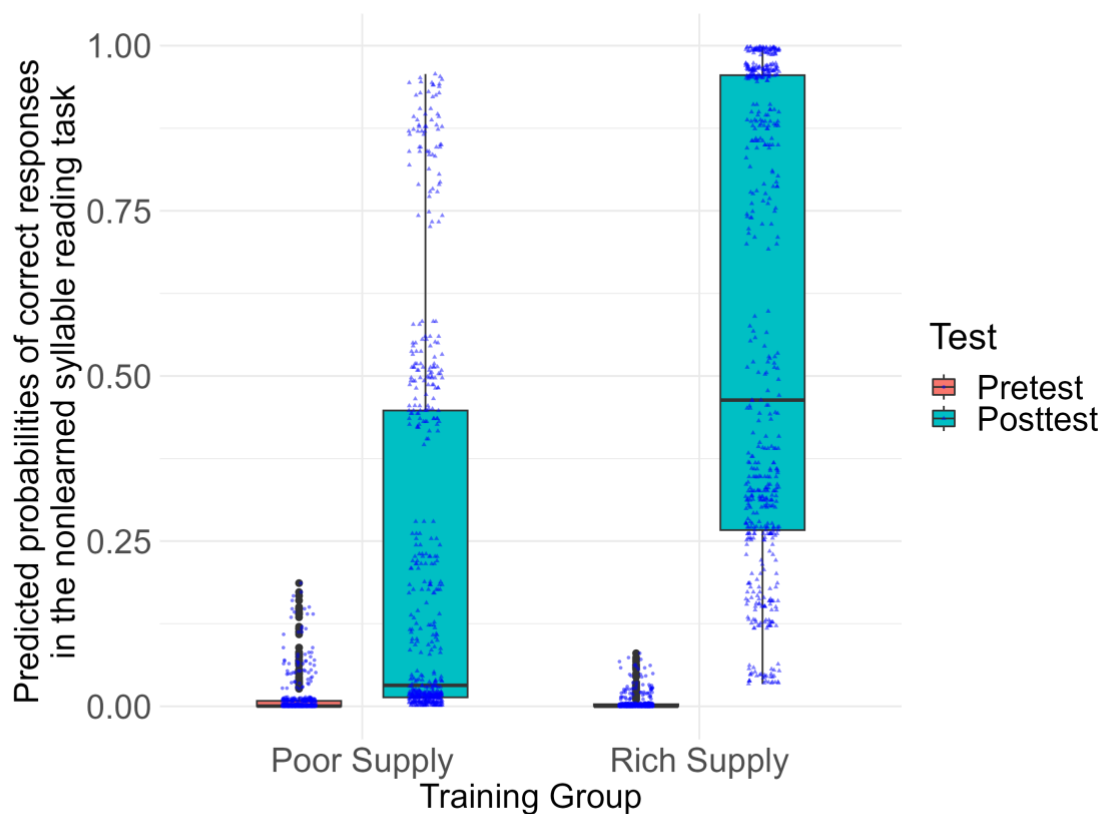
Upon conducting a more detailed analysis, we observed a significant effect of Test on learned syllable reading ($\beta = 6.77$, $SE = 1.24$, $Z = 5.47$, $p < .0001$). This result is not surprising since these syllables were taught in reading sessions. However, there was no significant effect of Training Group ($\beta = 1.64$, $SE = 1.33$, $Z = 1.23$, $p = 0.22$) and no significant interaction between Training Group and Test ($\beta = -0.67$, $SE = 1.26$, $Z = -0.53$, $p = 0.60$).

As for nonlearned syllable reading, there was a significant effect of Test ($\beta = 4.58$, $SE = 0.97$, $Z = 4.74$, $p < .0001$), indicating a significant improvement in nonlearned syllable reading. However, there was no effect of Training Group ($\beta = -0.96$, $SE = 1.98$, $Z = -0.49$, $p = 0.63$).

Importantly, the interaction effect between Training Group and Test was observed ($\beta = 4.24$, $SE = 1.89$, $Z = 2.24$, $p < .05$). This is consistent with our hypothesis that children trained with the “rich supply” would read nonlearned syllables better than those trained with the “poor supply.”

Figure 4.4

Boxplot presenting the proportion of correct responses in the nonlearned syllable reading task by group and by test conditions in Experiment 4.2



Phonemic Awareness

There was a significant effect of Test on phonemic awareness scores ($\beta = 4.15$, $SE = 0.45$, $Z = 9.25$, $p < .0001$), indicating a substantial improvement from the pretest to the posttest (see Table 4.7). There was no effect of Training Group ($\beta = 0.13$, $SE = 1.44$, $Z = 0.09$, $p = 0.93$).

The interaction effect between Test and Training Group was not significant ($\beta = -1.05$, $SE = 0.59$, $Z = -1.84$, $p = 0.07$). This may be due to the initially good level of phonemic awareness in participants, with a proportion of correct responses in the final phoneme elision task of 54.6%.

Table 4.7

Percentage of correct responses in preliteracy assessments by group and by test conditions in Experiment 4.2

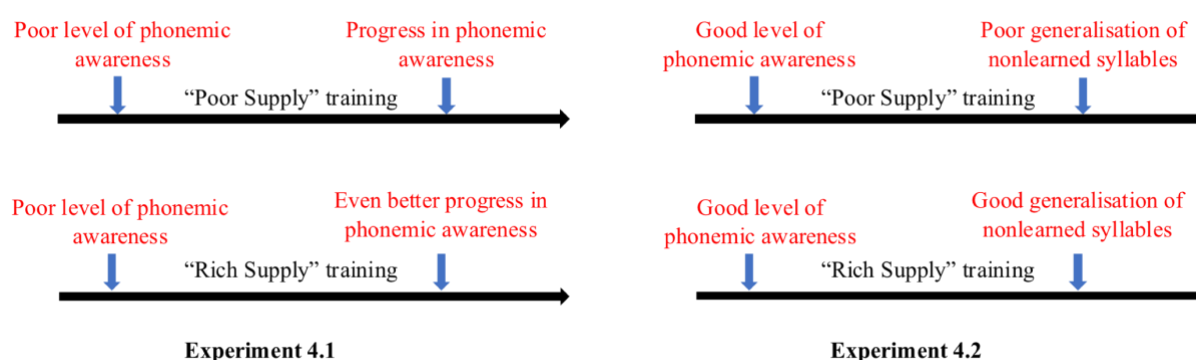
| Training group | Test | Letter name | Letter sound | Learned syllable | Nonlearned syllable | Phonemic awareness |
|----------------|-----------|-------------|--------------|------------------|---------------------|--------------------|
| “Rich supply” | Pretests | 91.9% | 39.7% | 3.7% | 0.7% | 62.2% |
| | Posttests | 94.1% | 50.0% | 69.9% | 52.2% | 76.5% |
| “Poor supply” | Pretests | 91.7% | 41.7% | 2.5% | 1.6% | 46.9% |
| | Posttests | 94.5% | 48.4% | 51.6% | 25% | 76.8% |

Discussion

The original aim was to examine the hypothesis from Experiment 4.1 with children at risk for reading disability who are not sufficiently exposed to print. However, Experiment 4.2 became opportunistic since the literacy assessment revealed that the participants already possessed a certain level of phonemic awareness. Consequently, the aim was adjusted to explore whether learning letters-to-syllable associations would trigger statistical learning, enabling children with a certain level of phonemic awareness to extract GPC regularities and, therefore, generalise nonlearned syllables. In line with the hypothesis, our findings demonstrated that children generalised more nonlearned syllables when learning with the “rich supply” as opposed to the “poor supply.” Thus, the current study reinforces the conclusion from Experiment 4.1, suggesting that learning letters-to-syllable associations triggers statistical learning, enabling children to extract GPC regularities.

Figure 4.5

Illustration of the main results in Experiments 4.1 and 4.2



Taking together the results of Experiments 4.1 and 4.2, as illustrated in Figure 4.5, if children start with a poor level of phonemic awareness, learning regular and effective letters-to-syllable associations, such as those in the “rich supply” training group, might them to make progress in phonemic awareness. When children possess a relatively good level of phonemic awareness, engaging in syllabic associative learning enables them to generalise nonlearned syllables. Importantly, by explicitly learning these syllabic associations, statistical learning, as a cognitive mechanism, functions constantly, as demonstrated by both progress in phonemic awareness and generalisation of nonlearned syllables.

At the pedagogical level, these studies offer insights about how best to structure reading education to help children transition from the pre-alphabetic phase to the alphabetic phase. Thus, further longitudinal study is needed within the present theoretical framework to enhance existing reading curricula.

CHAPTER 5: ON THE INFLUENCE OF STATISTICAL ORTHOGRAPHIC KNOWLEDGE ON

PHONOLOGY

The study was designed to explore the nature of the relationship between orthography and phonology during reading acquisition, specifically whether individuals' response on a phonological task are influenced by the interaction between orthography and phonology mediated through associative units. In Experiment 5.1, one hundred forty-four children from 1st to 5th grade and 61 undergraduate French-speaking students completed a syllable counting task for 80 CVC and CCVC acoustic monosyllabic pseudowords. The number of syllables in the pseudowords was ambiguous (either one or two) based on for acoustics criteria (Set A), given that the ending rhymes can be uttered and perceived with or without a vocalic schwa /ə/ (e.g., [flud] or [flu.də]), and based on orthographic criteria (Set B) since some of their ending rhymes could be frequently spelled with an "e" (e.g., [-uʃ]) while others are frequently spelled without an "e" (e.g. [-us]). Analysis of the results showed that (1) pseudowords were more frequently counted as one-syllable sequences when they had a high probability of not being spelled with an "e" rather than when they had a low probability of not being spelled with an "e" and (2) this effect increased with the reading level, confirming the influence of orthographic mental representation and literacy acquisition on phonological tasks. In Experiment 5.2, our findings showed that prereaders unambiguously counted pseudowords as one-syllable sequences, confirming that the ambiguity of the stimuli depended not on acoustics criteria but mainly on orthographic criteria and on literacy acquisition. In conclusion, our findings offer a new perspective on the relationship between phonology and orthography, suggesting a non-direct connection but, rather, a connection between mental phonological and orthographic representations that is mediated through associative units.

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EXPERIMENT 5.1

Introduction

The theoretical framework provided in Chapter 3 (see Figure 3.4, p. 70) suggests that two cognitive mechanisms are involved in early literacy acquisition: an associative learning mechanism, which functions to associate orthography with phonology, and a statistical learning mechanism, which serves to implicitly extract regularities from orthographic-phonological associations at the level of associative units. The studies in Chapter 4 provided evidence of the potential participation of the cognitive mechanism of statistical learning at the level of associative units by showing that children were capable of extracting GPC regularities from letters-to-syllable associations. Generally speaking, our studies initially explored the role of statistical learning in the progressive formation of the system of associative units.

The subsequent question should address how information is organised within the system of associative units, or “hidden units,” as described by Seidenberg and McClelland (1989). However, because these associative units are hidden, function unconsciously, and seemingly cannot be directly interrogated, studying how they are organised becomes a compelling issue. Instead of attempting to directly observe the organisation of the associative units, we can explore how individuals consciously reorganise ambiguous stimuli at either the orthographic or phonological level. The output observed from this will reflect how information is organised at the level of associative units that result from the interaction between orthography and phonology.

The illusory conjunction paradigm might serve as a method for observing how individuals unconsciously reorganise ambiguous stimuli provided at the orthographic level (see Figure 5.1). Scholars initially used this paradigm to explore the organisation of sublexical orthographic structure during word recognition. This paradigm involves swiftly presenting a word with letters in various colours, with participants being instructed to report the colour of a target letter.

For instance, as illustrated in Figure 5.1, the word “ANVIL” is briefly displayed with “ANV” in red and “IL” in blue, and participants are instructed to report the colour of the target letter “A”, which is red. In this case, the rapid presentation of the visual stimulus renders the perception of the target letter’s colour ambiguous, and participants may make an illusory conjunction error by reporting the blue colour for the target letter. The interpretation of this phenomenon is primarily based on two assumptions. One assumption posits that errors are influenced by positional bigram frequencies, i.e., orthographic redundancy. In this example, the bigram frequency for AN-NV-VI is high-low-high, respectively, and the low-frequency bigram “NV” marks the orthographic boundary between “AN” and “VIL” (e.g., Seidenberg, 1987). Conversely, scholars have suggested that there is an automatic perceptual segmentation of letter strings forming phonological syllables “AN” and “VIL”, as observed in English (Prinzmetal et al., 1986; Rapp, 1992). Doignon and Zagar (2005) proposed that phonological syllable units primarily influenced the perception of orthographic sublexical units, which are simultaneously modulated by orthographic redundancy. These results were replicated in Doignon-Camus et al. (2009) using monosyllabic words and pseudowords. The illusory conjunction paradigm might be utilised to observe how individuals unconsciously reorganise ambiguous stimuli provided at the orthographic level.

The current study chose to provide auditory stimuli at the phonological level in which the number of syllables can be ambiguous. This ambiguity arises due to the presence of an optional vowel in French, the schwa, noted as /ə/. The schwa may or may not be realised in the pronunciation of certain common words. For instance, the French word “cheval” (in English, “horse”) can be pronounced either [ʃval] or [ʃə.val]. Speakers can also add a word-final schwa when a word ends with a consonantal coda. For example, the French word “stop” (also “stop” in English) can be pronounced either [stop] or [sto.pə]. The current study utilised this property to create ambiguous auditory stimuli for a syllable counting task. As illustrated in Figure 5.2,

when presenting the pseudoword [skis] auditorily—whose number of syllables is ambiguous, given that the ending rhyme can be pronounced and perceived with or without the schwa /ə/—responses could be either one syllable [skis] or two syllables [ski.sə]. The divergent responses reflect how individuals reorganise ambiguous auditory stimuli.

Figure 5.1

Illustration of how an illusory conjunction paradigm reflects an individual's reorganisation of an ambiguous visual stimulus

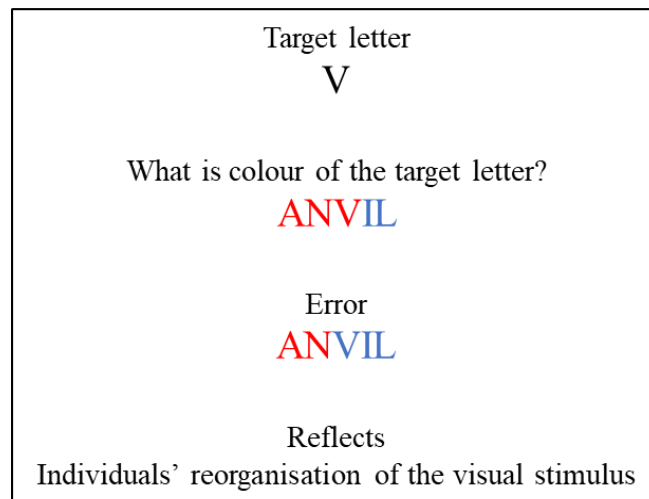
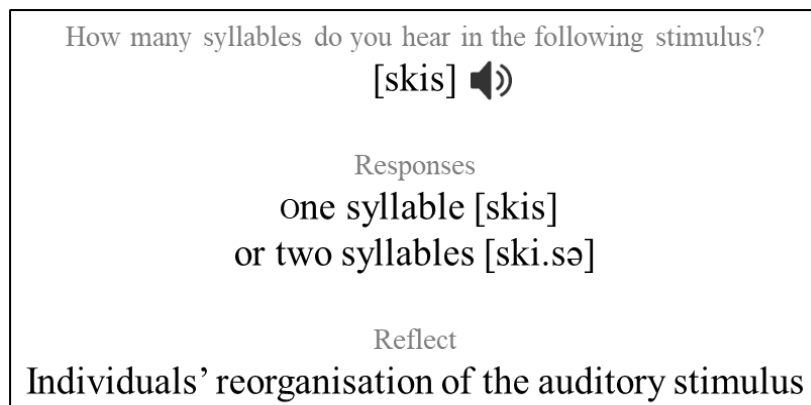


Figure 5.2

Illustration of how a syllable counting task reflects an individual's reorganisation of an ambiguous auditory stimulus



Our theoretical framework posits that individuals' reorganisation of ambiguous stimuli, provided at either the orthographic or phonological level, occurs within associative units, which develop through the interaction between orthography and phonology. The entirety of the associative units progressively forms, serving to dynamically generalise statistical properties as literacy levels evolve. Utilising a syllable counting task with ambiguous stimuli, we seek to examine whether responses to this task are subject to the influence of statistical orthographic properties, and, subsequently, whether this influence evolves during reading acquisition.

Literature review

Previous studies have explored the nature of the relationship between orthography and phonology during literacy acquisition. Neuroimaging studies have revealed the existence of a functional and anatomical link between phonemic and graphemic representations, which is strengthened by literacy acquisition (Dehaene et al., 2015; Dehaene et al., 2010). Furthermore, it has been established that participants are influenced by orthographic representations when asked to perform a variety of psycholinguistic tasks. These tasks, which demand an exclusive analysis of acoustic perceptual forms, include rhyme judgement (e.g., Donnenwerth-Nolan et al., 1981; Seidenberg & Tanenhaus, 1979), phoneme monitoring (e.g., Dijkstra et al., 1995; Hallé et al., 2000; Frauenfelder et al., 1990; Ziegler et al., 2004; Perre et al., 2009), syllable monitoring (e.g., Taft & Hambly, 1985), click detection (e.g., Bertelson, 1972), and spoken word recognition (e.g., Jakimik et al., 1985; Taft et al., 2008).

The influence of orthographic representations has also been intensively studied in relation to phonological awareness tasks (Liberman et al., 1974; Melby-Lervag & Lyster, 2012), which test the intentional ability to detect and manipulate units of speech (such as words, onsets-rhymes, syllables, and phonemes). Numerous studies have demonstrated a positive correlation between performance in writing and reading activities during literacy acquisition and in

phonological awareness (Adams, 1998; Brady & Shankweiler, 1991; Bradley & Bryant, 1983; Goswami & Bryant, 2016).

To our knowledge, the initial study to demonstrate that the orthographic representations of words contribute to the identification of their component phonological units was conducted by Ehri and Wilce (1980). In the first experiment of their study, native English-speaking fourth graders were tasked with segmenting and counting the phonemes of a list of word pairs, then blending and spelling them. In each pair, one word included an extra letter in its spelling, representing a potential additional sound. For instance, while both “rich” [rɪtʃ] and “pitch” [pɪtʃ] contained three phonemes, the “t” in “pitch” was the extra letter associated with a potential additional sound. The results indicated that the extra letter (i.e., the “t” in “pitch”) was often counted as an additional sound (i.e., four phonemes for “pitch” [pɪtʃ] vs. three phonemes for “rich” [rɪtʃ]). Moreover, when this extra sound was not identified, it was also incorrectly spelled (i.e., “pich” instead of “pitch”). To account for their findings, Ehri and Wilce proposed that literate individuals possess expert knowledge of word forms and spelling, which influences the organisation and nature of phonological representations, thereby impacting phoneme counting. Their interpretation suggested a direct relationship between orthography and phonology, instantiated at the word level.

Stuart (1990) further investigated the process and the factors underlying the use of orthographic representation during phonological awareness tasks. In her study, nine-year-old children, categorised as either good or poor spellers, were tested using a phoneme deletion task that utilised both words and pseudowords. The findings highlighted that good spellers not only outperformed their less skilled peers but also exhibited a higher tendency to produce orthographic responses. For instance, when asked to remove the letter “l” from the word “cold” [kɔʊld], they would alter the vowel and produce “cod” [kɒd], as opposed to maintaining the original vowel sound and creating “code” [kɔʊd]. Stuart proposed a dual-strategy model to

explain these results: she posited that while all children inherently applied a phonological strategy to delete phonemes, proficient spellers also engaged an auxiliary orthographic strategy to execute the task, particularly when dealing with actual words. Her interpretation also suggested a direct relationship between orthography and phonology, with varying proportions of participation in a phonological awareness task according to the literacy level.

Castles et al. (2003) not only confirmed the influence of orthographic information on phonological awareness tasks but also suggested that the underlying process is automatic rather than strategic. In their study, the researchers introduced a deletion task which contrasted orthographically transparent words with opaque ones, with items presented either in a block mixed randomly or in two separate blocks. For example, participants were asked to delete the /d/ from “dentist” [ˈdentɪst] and the /s/ from “fox” [fɒks]. The key finding was that participants performed better when dealing with transparent items than with opaque ones, regardless of whether they were presented in mixed or pure blocks. Castles et al. interpreted these results as an indication that literate individuals are unable to intentionally disregard orthographic information when undertaking phonological tasks, even when doing so is to their detriment.

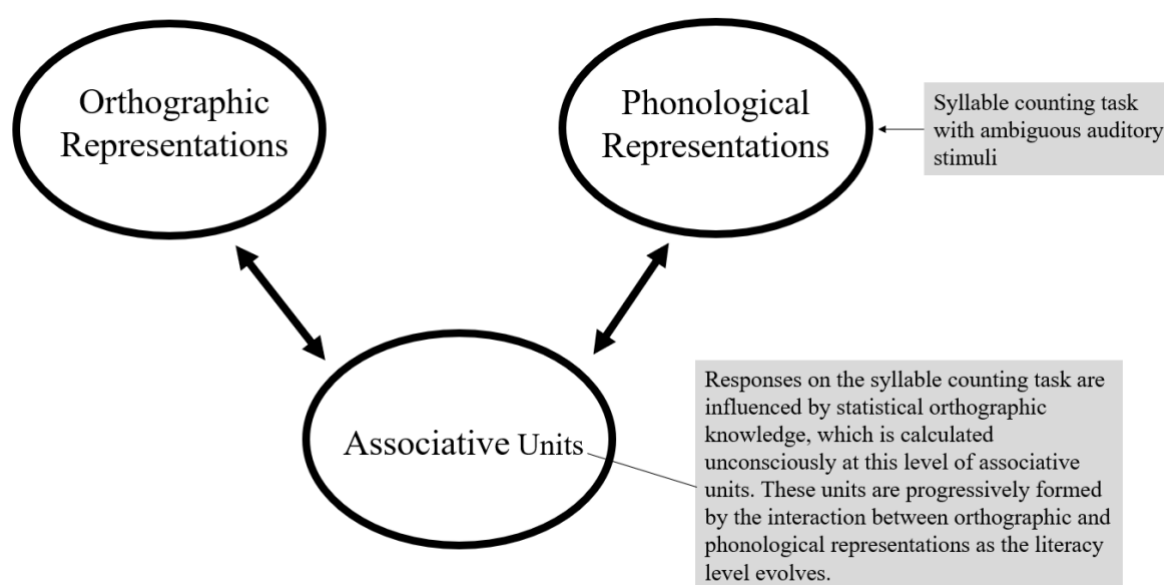
Consistent with Castles et al. (2003), Tyler and Burnham (2006) provided evidence indicating that the influence of orthography on phonological tasks is not subject to conscious control. They recorded reaction times during a phoneme deletion task, testing alphabetically literate individuals who were specifically instructed not to use orthography for responding. The data highlighted an automatic use of orthography since participants performed the task more slowly with orthographically mismatched stimulus-response pairs (e.g., “worth” – “earth”) than with matched pairs (e.g., “wage” – “age”), despite the instructions provided.

To summarise, previous studies have focused on the direct relationship between orthography and phonology, with a particular focus on how the orthography of individual words impacts phonological awareness tasks and exploring the inherent characteristics of this process.

Nevertheless, the relationship between orthography and phonology could be entwined in a more intricate manner, considering the possibility of generalising statistical properties from their interrelation.

Figure 5.3

Theoretical framework accounting for the influence of statistical orthographic knowledge on phonological awareness tasks



The influence of statistical orthographic properties on phonological tasks here can be conceptualised as “statistical orthographic knowledge,” which is essentially the frequency with which a sound sequence is orthographically rendered. To illustrate, within the French lexicon, rhymes exhibit varying probabilities of spelling endings, specifically with the letter “e”. For instance, the rhyme [uʃ] consistently ends in “e” in its written form, evident in “bouche” [buʃ], “touche” [tuʃ], “douche” [duʃ], “couche” [kuʃ], and so forth. Conversely, [is] only sporadically ends in “e,” as seen in examples like “dix” [dis], “six” [sis], “fils” [fis], “jadis” [ʒa.dis], but also “hisse” [lis], and “lisse” [lis].

This hypothesis is consistent with our theoretical framework (see Figure 5.3), which posits that statistical orthographic knowledge is generalised/calculated at the associative units level. These units, progressively formed through the interplay between orthographic and phonological representations, continue to develop as literacy levels advance.

The present study

The purpose of this study is to investigate whether responses on a syllable counting task with ambiguous pseudowords are influenced by statistical orthographic knowledge and, if so, how the influence develops as the literacy level evolves.

In general, in syllable counting tasks, all listeners agree on the number of syllables in an utterance. The unanimity in responses could be based on the perception and counting of the syllabic nuclei (e.g., the vowels), which most of the time is not problematic (Laks, 1995; Morais, 2021). However, this process of counting based on the perception of the syllabic nuclei can become difficult when the presence of the nucleus is ambiguous. This occurs in French when dealing with the phenomenon of word-final schwa.

As previously discussed, the schwa sound /ə/ can appear both in the middle and at the end of a word in French. When it appears in a word-final position, the French word-final schwa is considered by linguists to be an epenthetic segment (see Hutin et al., 2021). In a corpus-based study investigating the distribution of word-final schwa in Standard French, Hutin et al. (2021) found that a word-final schwa was observed in 13.40% of occurrences of words ending in a consonantal coda, especially when the ending consonant was a voiced plosive (e.g., 23.91% of schwas after /d/). Voiced plosives are acoustically and auditorily poor; their main feature for place of articulation is carried by the adjacent vowels. Consequently, plosives in French, especially voiced plosives followed by a pause, are sometimes uttered with a schwa, resulting

in a C(C)VC⁹ pattern. This linguistic phenomenon gives rise to multiple phonetic realisations and perceptions, with or without the schwa (Racine & Grosjean, 2005).

For French listeners exposed to the schwa phenomenon, the perception of syllabic nuclei might change, and consequently rendering the syllable counting task ambiguous. To investigate this possibility, we propose Experiment 5.1 with a set of stimuli (Set A, see Appendix D), employing CVC and CCVC monosyllabic pseudowords ending in a voiced plosive coda (e.g., [flud]) that could potentially be followed by a perceptual final schwa and perceived either as a C(C)VC monosyllabic pseudoword (i.e., [flud]) or as a C(C)V.Cə bisyllabic pseudoword (i.e., [flu.də]).

To observe the potential influence of statistical orthographic knowledge on the syllable counting task, we constructed a second set of monosyllabic pseudowords (Set B, see Appendix D) for Experiment 5.1. All the pseudowords in this set are acoustically monosyllabic C(C)VC ending in fricative consonants, entailing no vowel trace in the speech spectrum and, consequently, no acoustic ambiguity in the judgement. In this set, the source of ambiguity resides in the statistical distributions of rhyme spellings in words. As we mentioned above, in French, some words end in rhymes that are frequently written with an “e” at the end of the word (e.g., the rhyme [-uʃ] in [duʃ] “douche”, in English “shower”), while others are frequently written without an “e” (e.g., the rhyme [-is] in [dis] “dix”, in English “ten”). We compared patterns of different frequencies with which the rhymes were written in the French lexicon. If listeners are sensitive to statistical orthographic knowledge, they should be more inclined to answer that acoustic stimuli are monosyllabic for pseudowords ending in a rhyme having a higher probability that its spelling does not end in “e” (e.g., [skis] ending in [-is]) than for stimuli ending in a rhyme with a lower probability that its spelling does not end in “e” (e.g., [spuʃ] ending with [-uʃ]).

⁹ C: consonant, V: vowel, ə: the schwa sound

Finally, Experiment 5.1 also examines how this potential influence changes during literacy acquisition. For Set A, we did not formulate any hypothesis, as the question posed with Set A is not related to any orthographic knowledge. For Set B, however, we expected to observe an effect attributable to literacy acquisition. Literate adults and children in the process of learning to read and write do not possess the same statistical orthographic knowledge, which is generalised during the progressive establishment of the relationship between orthography and phonology. Consequently, it is expected that the influence of statistical orthographic knowledge should intensify with literacy acquisition, impacting the results of Set B. To assess the role of literacy skills in the task, we tested four groups of French-speaking participants, each at different stages of literacy acquisition. Additionally, to broaden our analysis, we proposed Experiment 5.2, focusing solely on Set B and testing a group of prereaders in kindergarten.

Methods

Participants

In this experiment, participants are one hundred forty-four children attending primary school (73 1st graders: 37 girls, 36 boys, $M_{\text{age}} = 7$ years 1 month, $SD = 0;3$; 71 3rd graders: 37 girls, 34 boys, $M_{\text{age}} = 10$ years 11 months, $SD = 0;3$) and 80 undergraduate students from the University of Lorraine (70 females, 10 males, $M_{\text{age}} = 20$ years 7 months, $SD = 1;10$). They were native French speakers with no reported hearing problem and normal or corrected vision. All adult participants verbally agree to participate in the study after reading an informed consent form. All adult participants verbally agreed to participate in the study after reading an informed consent form. The school supervisors and parents or legal guardians of the child participants provided written informed consent prior to their inclusion in the study.

A phonological tapping task was administered to all participants to assess syllable awareness. Participants were required to identify the number of syllables in five non-words

spoken by the experimenter by tapping accordingly. Nine 1st Grade child participants, who succeeded with fewer than five non-words, were excluded from the final sample.

Children’s literacy levels were assessed using the “Alouette” test (Lefavrais, 2005), a standardised French assessment of reading level. During this task, children were instructed to read aloud 265 words as accurately and as quickly as possible within a three-minute window. Both error rates and speed were utilised to assign reading levels, independent of the actual school-grade level. This assessment yielded eight reading level groups. From these, three reading level groups with sufficient numbers of subjects were selected: a 1st grade reading level group with 36 children (all 1st graders), a 2nd grade reading level group with 33 children (27 of whom were 1st graders and 6 were 3rd graders), and a 5th Grade reading level group with 26 children (all 3rd graders). The characteristics of the three retained reading level groups are summarised in Table 1. Five reading level groups were excluded from the analysis due to insufficient participant numbers (3rd grade = 10, 4th grade = 8, 6th grade = 11, 7th grade = 9, and 8th grade = 2, totalling 40 children).

Table 5.1

Characteristics of reading level groups in Experiment 5.1

| Reading Level | 1 st Grade | 2 nd Grade | 5 th Grade | Literate Adults |
|--|-----------------------|-----------------------|-----------------------|-----------------|
| Number | 36 | 33 | 26 | 61 |
| Males; Females | 21;15 | 15;18 | 13;13 | 5;56 |
| Mean chronological age in years; months (SD) | 7;1 (0;4) | 7;7 (0;4) | 10;12 (0;6) | 24; 4 (1;5) |

Adult participants’ literacy levels were assessed using the same “Alouette” test (Lefavrais, 2005), but with a different scoring system – the CTL score¹⁰, which takes both

¹⁰ CTL = (C*180)/TL; with C = the number of words correctly read, and TL = the reading time; max = 180 s

reading accuracy and speed into account (Cavalli et al., 2017). Nineteen adult participants who did not meet the criterion score (400, which guarantees no reading disabilities or problems) were excluded from the final sample. The final sample comprised 61 adults. Their characteristics are summarised in Table 5.1.

Materials

Two sets of 40 pseudowords, Set A and Set B, were created for presentation as acoustic stimuli. Set A and Set B were analysed separately due to their distinct experimental purposes. The primary goal of Set A was to determine whether the syllable count of the pseudowords was ambiguous for participants. The main objective of Set B was to investigate whether statistical orthographic knowledge might influence responses to the syllable counting task and whether this influence would vary with increasing reading levels.

All stimuli were recorded by a native speaker—a young female majoring in speech therapy in Nancy, France. The speaker was instructed to pronounce the pseudowords in a neutral manner, maintaining a consistent speech rate and intonation pattern. Pronunciation of the pseudowords was executed in a list-like manner. The recorded speech signal was annotated with IPA symbols using Transcriber software and segmented into sounds through an automatic forced speech alignment between the speech signal and its constituent sounds, utilising Astali software (<http://ortolang108.inist.fr/astali/>). Finally, the speech signal was automatically segmented into separate auditory files, each containing a single stimulus, using a signal processing script.

Materials also included six training items (see Appendix F) and 40 fillers (see Appendix G). Fillers consisted of unambiguous monosyllabic and bisyllabic open syllables. Six native French speakers verified that all stimuli on the list had no semantic meaning.

Set A

Set A included 40 C(C)VC pseudowords (see Appendix C). Three voiced plosives were selected as codas (-C) of the pseudowords: /d/, /g/, and /b/. Among all plosive codas, these three voiced plosives are most frequently followed by a schwa, according to a corpus-based study on the distribution of word-final schwa in Standard French (Hutin et al., 2021). Each coda was combined with consonantal onsets (C- or CC-) and a vowel nucleus (-V-) to form pseudowords (see Table 5.2). Acoustically, the stimuli contained neither a schwa-like vowel nor a mitigated schwa in the speech signal when the deletion was not possible.

Table 5.2

Plosive codas used in Set A

| Coda | Example | Syllable structure | % Schwa ^a |
|------|---------------|--------------------|----------------------|
| /d/ | [flud], [pud] | CCVC, CVC | 23.91 |
| /g/ | [klɛg], [fag] | CCVC, CVC | 14.27 |
| /b/ | [glab], [fɔb] | CCVC, CVC | 11.32 |

^a % Schwa represents the proportion of the realization of final-schwa in words ending in the same coda, according to the corpus-based study of the distribution of the word-final schwa in Standard French (Hutin et al., 2021).

Set B

Set B included 40 C(C)VC pseudowords (see Appendix E), ending in the fricative codas /f/, /s/, and /ʃ/. Rhymes (-VC) were selected based on the probability of their orthographic forms in French words. The frequency of words ending in the same rhyme was collected from the French database Lexique3 (New et al., 2004). Ten rhymes, each having different probabilities of spelling without an “e”, were selected (see Table 5.3). Each rhyme was combined with four

onsets, which were either a single consonant (C-) or a two-consonant cluster (CC-), to create acoustic pseudowords.

During the recording of this set, the speaker was instructed not to produce the schwa at the end of the items. We controlled the absence of schwa for each items using PRAAT software (Boersma & Weenink, 2023).

Table 5.3

Rhymes used in Set B

| Rhyme | Probability that spelling does not end in “e” | Coda | % Schwa ^a | Example | Syllable structure |
|-------|---|------|----------------------|---------|--------------------|
| [ɛf] | 0.982 | /f/ | 6.83 | [blɛf] | CCVC |
| [us] | 0.785 | /s/ | 8.03 | [slus] | CCVC |
| [ys] | 0.455 | /s/ | 8.03 | [fʁus] | CCVC |
| [is] | 0.396 | /s/ | 8.03 | [slis] | CCVC |
| [uf] | 0.292 | /f/ | 6.83 | [kluf] | CCVC |
| [iʃ] | 0.179 | /ʃ/ | 7.25 | [fliʃ] | CCVC |
| [ãs] | 0.148 | /s/ | 8.03 | [glãs] | CCVC |
| [uʃ] | 0 | /ʃ/ | 7.25 | [spuʃ] | CCVC |
| [ãʃ] | 0 | /ʃ/ | 7.25 | [stãʃ] | CCVC |
| [yʃ] | 0 | /ʃ/ | 7.25 | [slyʃ] | CCVC |

^a % *Schwa* represents the proportion of final-schwa in words ending in the same coda, according to the corpus-based study of the distribution of a word-final schwa in Standard French (Hutin et al., 2021).

Procedure

The experiment was conducted on a computer running the open-source software OpenSesame (Mathôt et al., 2012). All participants listened to stimuli through headphones, with the volume set to level 16 out of 100.

Child and adult participants were tested individually in a quiet room. Stimuli were presented to the participants in a fixed pseudorandom order in a single session. Participants were instructed to respond spontaneously: if they perceived the stimulus as one syllable, they were to press the “q” key (labelled with a “1”), and if they perceived it as two syllables, they were to press the “m” key (labelled with a “2”) on AZERTY keyboards. The session began with a training block composed of six trials, followed by two testing blocks, each consisting of 60 trials. The session lasted approximately 30 minutes. No feedback was provided.

Results

All participants achieved more than 80% correct answers on the non-ambiguous filler.

For Set A, 47.6% were counted as one-syllable sequences and 52.4% were counted as two-syllable sequences despite reading level. The analysis of results for Set A directly confirms the ambiguity in the number of syllables in acoustic stimuli due to the presence of a potential word-final schwa.

We could expect that syllable-counting responses might be related to the probability of being followed by schwa, a probability that was analysed by Hutin et al. (2021). However, as shown in Table 5.4, there was no relationship between the probability of being followed by schwa and the proportion of one-syllable responses across all reading levels.

We fitted a mixed effects binomial logistic regression model using the GLMER function from the lme4 package (Bates et al., 2015) in R version 4.1.1 (R Core Team, 2021). The model included participants and items as random effects. We performed a likelihood-ratio test which showed that the inclusion of random effects was justified ($p = 0$). AIC of baseline model with

random effects was smaller than that of a baseline model without random effects (without random effects = 8677.634; with random effects of items and participants= 6007.415). Predictors of the model were reading level and probability that spellings do not end in “e”, as well as their interaction. Comparisons between multiple models showed that the integration of both variables as well as their interaction improved model fit (AIC with interaction = 5943.092; without interaction = 5959.072). The model predicted one-syllable responses; literate adults were the reference level of the model. Results showed a significant interaction between reading level and spelling (Figure 5.4). We changed the reference level of the model to examine the effect of spelling in each reading level group. Effect of spelling was significant and positive for literate adults ($\beta = 0.011$, $SE = 0.002$, $z = 5.762$, $p < .001$) and for 5th graders ($\beta = 0.009$, $SE = 0.002$, $z = 3.685$, $p < .001$). It was not significant for 2nd graders ($\beta = 0.002$, $SE = 0.002$, $z = 1.156$, $p = 0.248$) or 1st graders ($\beta = 0.001$, $SE = 0.002$, $z = 0.336$, $p = 0.737$).

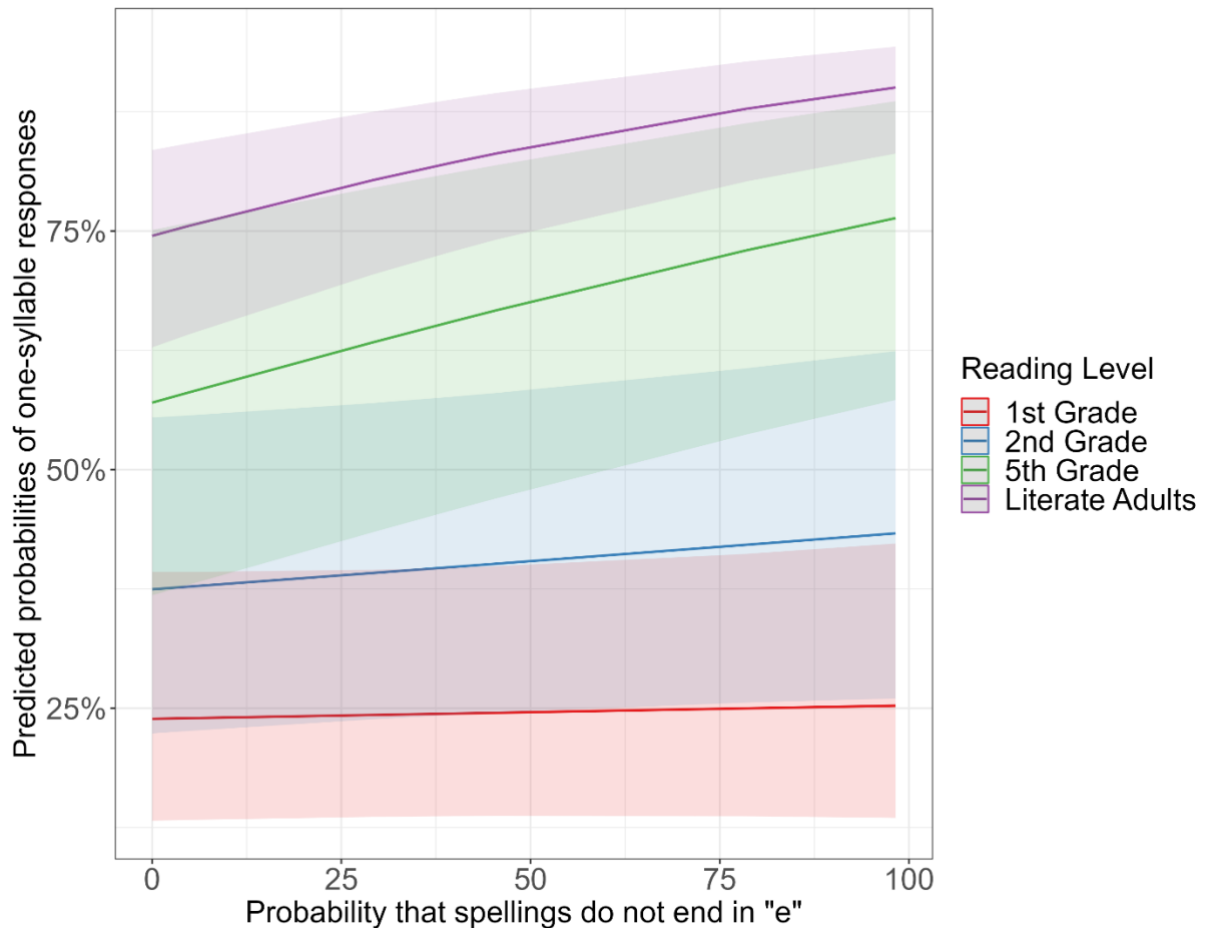
Table 5.4

Proportion of one-syllable responses for pseudowords ending in plosives codas

| Plosive codas | % Schwa | 1 st Grade | 2 ^{ed} Grade | 5 th Grade | Literate Adults |
|---------------|---------|-----------------------|-----------------------|-----------------------|-----------------|
| /b/ | 11.32% | 37.04% | 37.12% | 58.33% | 65.08% |
| /g/ | 14.27% | 34.90% | 35.23% | 56.01% | 59.82% |
| /d/ | 23.91% | 31.94% | 38.13% | 54.81% | 64.48% |

Figure 5.4

Regression graph showing the effect of the interaction of reading level and probability of spelling the rhyme without e on the probability of one-syllable responses in Experiment 5.2



Discussion

In Experiment 5.1, we examined the influence of statistical orthographic knowledge on a syllable counting task, presenting two sets of stimuli (Set A and Set B) to different groups of participants, ranging from 1st Grade reading level to literate adults.

With Set A, we investigated whether the syllable counting of pseudowords was ambiguous for participants. The results confirmed that the stimuli of our tasks were indeed ambiguous. Furthermore, they revealed that responses of one or two syllables were unrelated to the probability of the presence of a word-final schwa, a probability analysed in the oral corpus

data by Hutin et al. (2021). This highlighted that the acoustic environment was not the source of the participants' counting.

For Set B, data showed that the effect of statistical orthographic knowledge was observed in participants possessing substantial knowledge of orthography (i.e., 5th Grade and adult-like reading levels) and not in beginning readers (1st and 2nd reading levels). As familiarity with reading grows, we observe a parallel increase in monosyllabic responses and in the influence of orthographic forms (see Figure 5.4). The model revealed that the influence of statistical orthographic knowledge was not significant for the 1st and 2nd grade reading levels but became significant for the 5th Grade reading level and literate adults (see Chetail & Content, 2017 for similar developmental tendency). Before discussing the implications of this pivotal result, we shall first seek to understand why participants in 1st and 2nd Grade reading level were more inclined to respond that pseudowords were bisyllabic, when stimuli were generally monosyllabic according to linguistic and acoustic criteria. To delve further into the explanation of these results, we conducted Experiment 5.2 in prereaders.

EXPERIMENT 5.2

Introduction

The results of two-syllables responses in Experiment 5.1, observed in 1st and 2nd graders, might depend on teaching methods employed in early school years. Indeed, in the initial years of French primary school, numerous spelling errors, particularly in word endings, are commonly observed (Sénéchal, Gingras & L'Heureux, 2016). To facilitate the learning process and reduce such errors, teachers often emphasise final codes, typically by adding a word-final schwa. For example, with a word like “carte” ([kart], in English “card”) — where “te” is the ending bigram, with the “t” being pronounced and not the “e” — teachers stress the word ending, introducing a schwa vowel into the pronunciation (i.e., [kartə]) to ensure children write the final letter “e”. Furthermore, to support the encoding of this orthographic final “e”, they repeat the word, syllabifying it into two syllables, [kar]-[tə], even though it is a monosyllable in speech. All these explicit instructions, provided at the beginning of literacy acquisition, might result in a two-syllable count for monosyllables ending with a rhyme that could be spelled with an “e”. To rule out the opposing hypothesis, we proposed the same experiment to a group of pre-readers in kindergarten. We hypothesised that kindergarteners, who have not yet received explicit writing instructions, should count one syllable for our acoustic pseudowords.

Methods

Participants

Twenty-four children in their final year of kindergarten participated in this study, comprising 12 girls and 12 boys, with an average age of 5 years and 2 months. All participants were native French speakers with no reported hearing issues and either normal or corrected vision. Parents or legal guardians were sent a detailed letter about the study along with a consent

form; participation proceeded only with returned, signed forms. Two participants did not complete the entire study due to an unwillingness to continue.

We assessed the participants' letter knowledge and syllable reading ability. Specifically, they were asked to name eight letters ("A", "I", "O", "U", "B", "F", "T", and "S"), produce the sounds of four consonant letters ("B", "F", "T", and "S"), and read 16 consonant-vowel syllables ("BA", "BI", "BO", "BU", "FA", "FI", "FO", "FU", "TA", "TI", "TO", "TU", "SA", "SI", "SO", and "SU"). The results showed that they were prereaders with high letter knowledge (the average score was 7.6 out of 8), low letter sound knowledge (the average score was 0.4 out of 4), and low syllable reading knowledge (the average score was 1.2 out of 16).

Materials and procedure

The materials comprised Set B, along with twenty fillers selected from Experiment 5.1 (see Appendix G). The procedure was identical to that in Experiment 5.1, with the exception that participants were instructed to count the number of syllables by clapping their hands and responding verbally. The experiment was conducted over a duration of 15 minutes in a single testing session.

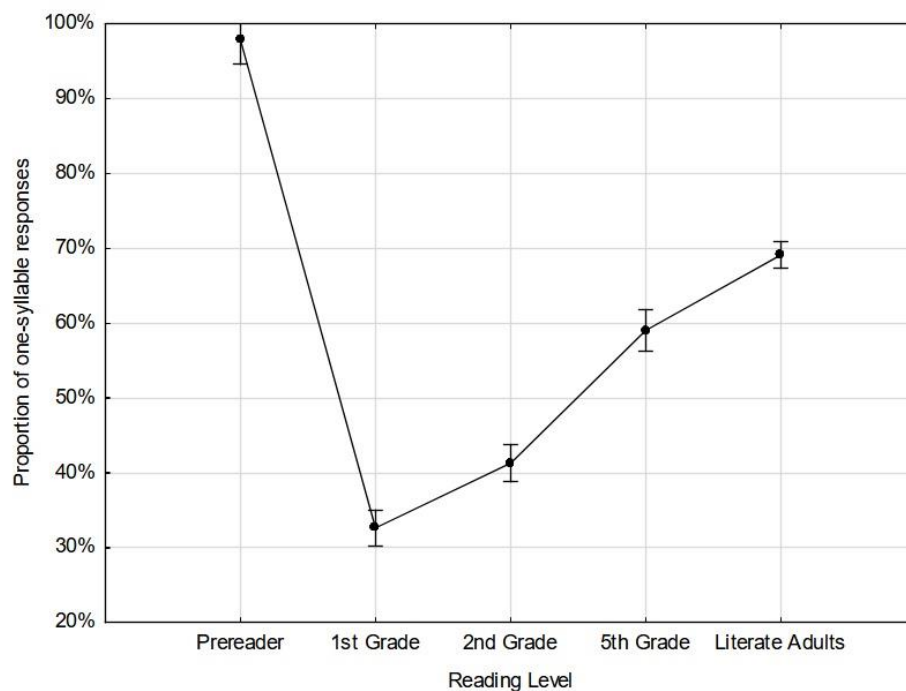
Results

Firstly, four participants who did not achieve more than 80% correct answers on the filler items were excluded from the analysis. Prereader participants counted 98% of ambiguous monosyllables as a one-syllable sequence, contrasting sharply with the 32.6% observed in participants at a 1st Grade reading level. This aligns with our hypothesis that, prior to formal schooling and the explicit teaching of written French, prereaders perceive all stimuli as monosyllables.

Figure 5.5 illustrates the developmental evolution of the one-syllable responses for Set B with the results of Experiment 5.1 included. For pre-readers the stimuli were not ambiguous; they were considered simple monosyllabic sequences. Only from 1st Grade, the proportion of one-syllable responses increased as the reading level increased (the proportion of one-syllable responses in 2nd Grade, 5th Grade, and literate adults were 41.3%, 59.0%, and 69.1%, respectively). It is solely in 1st Grade, when explicit teaching of writing starts, that these stimuli become ambiguous, giving rise to two-syllables responses.

Figure 5.5

Proportion of one-syllable responses in prereaders (Experiment 5.2, Set B), 1st Grade, 2nd Grade, 5th Grade and Literate Adults (Experiment 5.1, Set B)



Discussion

According to our data, prior to 1st Grade, children's responses were governed by acoustics criteria, predominantly resulting in one-syllable responses. Only upon commencing

the 1st grade do the stimuli become ambiguous, allowing a C(C)V.CV two-syllable count. This ambiguity in the stimuli did not disappear with literacy acquisition since it was observed in 2nd graders, 5th graders and even in literate-adult reading levels.

In some way, the difference in syllable counting observed between prereaders and 1st grade is due to the reading acquisition, given that the explicit instruction of reading provided by teachers during the initial years of primary school guide phonological counting. The explicit instructions provided at the beginning of literacy acquisition could entail a phonological representation that anchors the ending vowel [ə] to a C(C)V.Cə structure, resulting in a two-syllable count for C(C)VC monosyllables.

General discussion

The purpose of this study was to investigate whether responses to a syllable counting task, utilising ambiguous pseudowords, are influenced by statistical orthographic knowledge and, if so, to explore how this influence develops as literacy levels evolve.

For this purpose, we initially explored, using Set A in Experiment 5.1, whether the syllable counting of the pseudowords was ambiguous for participants. The findings indicated not only that the potential inclusion of a word-final schwa rendered the task ambiguous but also that participants' responses of one or two syllables were not related to the probability of a word-final schwa's presence, a probability calculated in the corpus analysis study by Hutin et al. (2021).

In Experiment 5.1, Set B, our findings revealed an influence of statistical orthographic properties on responses to a syllable counting task. All the pseudowords in Set B were acoustically C(C)VC monosyllables ending in fricative consonants, not entailing any vowel trace in speech spectrum. However, the final syllable of the pseudowords, with which they rhyme, can be spelled in different ways. Listeners were more inclined to perceive acoustic

stimuli as monosyllabic for pseudowords ending in a rhyme having a higher probability of not spelled with a terminal “e” (e.g., [kluf] ending in [-uf]) than for pseudowords ending in a rhyme having a lower probability of not spelled with a terminal “e” (e.g., [spu] ending in [-u]). Moreover, this effect of statistical orthographic knowledge intensifies as individuals’ reading level advances. Specifically, statistical orthographic knowledge notably influence syllable counting at the 5th grade and literate adult reading level, but not at the 1st and 2nd grade reading level.

Regarding the evolution of the responses to the syllable counting task, the curve was manifestly clear. Initially, as shown in Experiment 5.2, when individuals were prereaders, the pseudowords were unambiguously identified as one syllable. These responses were formulated based on acoustic criteria when individuals had not been exposed to any orthography. However, once individuals commenced receiving explicit reading and writing instruction and attained a 1st grade reading level, the occurrence of two-syllable responses notably increased. This may particularly be ascribed to the emphasis instructors place on the final-word schwa during the initial years of schooling, ensuring that reading learners do not overlook the silent letter “e” in word spellings. As individuals continue to acquire literacy knowledge, until achieving a literate level, two-syllable responses were progressively overtaken by one-syllable responses. However, it is worth noting that unlike prereaders, who were not sensitive to the ambiguity, literate adults only achieved a proportion of about 70% in one-syllable responses.

At first glance, our findings might align with previous studies, providing evidence of an influence of the orthographic form of words on responses to phonological awareness tasks (Ehri & Wilce, 1980; Castle et al., 2003; Stuart, 1990; Tyler & Burnham, 2006). However, in our experiments, the orthographic properties of the stimuli cannot be attributed to the lexical level. Firstly, the stimuli were acoustic pseudowords with no defined spelling pattern. Secondly, the orthographic information did not pertain to a particular lexical representation but to the

frequency with which the phonological rhymes were spelled across the lexicon. This implies that phonological responses could be sensitive to statistical orthographic knowledge in addition to lexical orthographic knowledge, as demonstrated in previous studies. This suggests a more complex interaction between phonological and orthographic mental representations than a mere direct relationship between them.

This complex interaction between orthography and phonology might thus be generated through a set of associative units, as suggested in our theoretical framework. In the present study, individuals were provided with acoustic pseudowords, the number of syllables in which was ambiguous at the phonological level; their one- or two-syllable responses to the syllable counting of these pseudowords reflected how they reorganised them. Here, the reorganisation of pseudowords is influenced by the probability of their spellings ending in “e”. This type of statistical orthographic representation is not likely generalised at the orthographic level but is calculated unconsciously at the level of associative units mediating orthography and phonology.

The interaction effect between statistical orthographic knowledge and reading level suggests that the formation of the entire system of associative units was a progressive process resulting from cumulative learning of orthographic-phonological correspondences. In prereaders, who have not begun to learn orthographic-phonological associations, there was no value at the level of associative units. Without an assigned value at this level, prereaders cannot generalise statistical orthographic properties. Consequently, their responses to the syllable counting task depend on the acoustic criteria, limited to the phonological level.

One-syllable responses in prereaders turning brusquely to two-syllable responses in children with a 1st grade reading level is likely explained by the explicit instruction of reading and writing by the teachers, however, the re-dominance of monosyllable response as individuals’ literacy level cannot be explained by our theoretical framework. We have not any specific

hypothesis of this evolution. Future studies are requisite to further explore processes underlying this evolution.

The present study serves as a significant starting point by suggesting a non-indirect relationship between orthography and phonology. By providing a syllable counting task with pseudowords, wherein the number of syllables was ambiguous, we furnished evidence of the potential existence of associative units that mediate between orthography and phonology, as reflected by the reorganisation of these pseudowords. How these pseudowords are reorganised presents an important issue for future studies. It is also worth reflecting on how an ambiguous phonological awareness task can be designed in other languages, and how individuals speaking other languages reorganise it within the associative units.

CHAPTER 6: GENERAL DISCUSSION

The research presented in this thesis delves into the cognitive mechanisms underpinning early literacy acquisition. In Chapter 1, we revisited the inner structure of the world's writing systems, challenging the traditional understanding of grapheme-phoneme correspondences in alphabetic writing systems. Chapter 2 provided an overview of both explicit and implicit learning in reading acquisition. We emphasised that the mnemonic dimension of explicit learning fosters a conducive environment for implicit learning mechanisms. Building on this foundational understanding, Chapter 3 introduced a theoretical framework that captures the initial stages of learning to read. Within this framework, we posed research questions about the role of statistical learning and the nature of the relationship between orthography and phonology. Chapters 4 and 5 empirically addressed these research questions. In this concluding chapter, we offer a synopsis of our primary findings. This is complemented by a discussion on the theoretical implications of our results. We will then reflect on the study's limitations and propose future direction for research.

PLAN OF CHAPTER 6

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Overview of main findings

How to learn to read is profoundly influenced by the inner structure of writing systems, which was studied through a linguistic approach (e.g., DeFrancis, 1989; Gelb, 1963). The transition from logography to phonography marks the emergence of full writing systems. The traditional perspective views the invention of writing systems as an *evolutionary* process, with alphabetic writing systems considered the most advanced form of *phonetization*. Alongside the systematisation in writing of speech sound, the inner structure of writing systems has been defined by the one-to-one correspondence between elements of writing and elements of speech. With this development, elements of speech were seen as progressively refined, evolving from words, to syllables and ultimately to phonemes. In alphabetic writing systems, the one-to-one correspondence has thus been defined between graphemes and phonemes. This linguistic approach conventionally determines the foundation of reading instruction in alphabetic writing systems, known as the alphabetic principle.

However, as analysed in Chapter 1, with the linguistic approach that defines the nature of the inner structure of writing as having a direct association between written symbols and phonological units, there has never been a consensus on the classification of writing systems. If we were to assume that a universal approach to describe the inner structure of all writing systems should exist, it might suggest that this linguistic approach is incomplete. Upon revisiting the invention of full writing systems, we propose a novel cognitive approach to describe their inner structure. We adopt the concept of double articulation (Martinet, 1960/1961), applying it to writing systems. The first level of articulation refers to the *sign* in Saussurean terms, while the second level pertains to the *syllable* rather than the *phoneme*. Within the inner structure of writing systems, one cognitive path involves a direct association between graphemes and signs. For instance, in Chinese, a simple character in itself represents a *sign*; in alphabetic writing, a monosyllabic word acts as a *sign*. This direct association

typically represents only a minor part of the writing system. For this segment of writing, memorisation of the correspondence between graphemes and signs is essential. Chinese children begin reading by learning simple characters, a process that demands significant memorisation of orthographic-phonological pairs (e.g., Chow, 2014; Li et al., 2009; Liu et al., 2021). Similarly, in English, a large majority of the most frequent monosyllabic words have often inconsistent and irregular grapheme-phoneme correspondences, requiring children to memorise the correspondence between a monosyllabic word and its pronunciation.

Another cognitive path involves combining graphemes to represent either signs or syllables. Using Chinese writing as an example, combination of phonetic components and semantic radicals constitutes more than 90% of Chinese characters, which DeFrancis (1989) term semantic-phonetic compound characters. Each character also represents a syllable. In alphabetic writing, combinations of graphemes (i.e., letters) form the syllables in polysyllabic words. These syllables tend to exhibit more regular and consistent grapheme-phoneme correspondences.

The cognitive system of writing is associative, embedding a network of associations between orthographic and phonological representations. At the phonological level, there are two units of articulation: the sign and the syllable. Following this conception, reading involves the combination of graphemes, which guides readers toward the second unit of articulation: the syllable. We hypothesise that children begin learning to read by associating letters or letter strings with phonological syllables. This associative learning might enable them to detect and extract grapheme-phoneme correspondences.

This hypothesis is motivated not only by the cognitive approach to the inner structure of writing systems (see Chapter 1) but also by the reinterpretation of both explicit and implicit aspects of learning to read (see Chapter 2). We particularly emphasise the *mnemonic* dimension of explicit instruction in tandem with its *explicative* dimension. The *mnemonic* dimension of

explicit instruction necessitates that children memorise orthographic-phonological pairs. This often-overlooked dimension might provide conducive environments for implicit cognitive mechanisms, including statistical learning. Upon reviewing statistical learning in the literature, one potential pathway suggests a causal relationship between statistical learning and reading ability: statistical learning may enable children to detect and extract regularities in grapheme-phoneme correspondences (Apfelbaum et al., 2013; Arciuli & Sampson, 2012; Siegelman et al., 2020). Furthermore, to empirically test the “syllabic bridge” hypothesis, Vazeux et al. (2020) demonstrated that letter-to-syllable associative learning led to a more significant increase in phonemic awareness than letter-to-phoneme associative learning in prereaders. Taken together, we hypothesise that letter-to-syllable associative learning might stimulate statistical learning, enabling prereaders to extract grapheme-phoneme correspondences. The experiments in Chapter 4 were designed to test empirically this hypothesis.

Crucially, within our theoretical framework, the reorganisation of associations between letter strings and phonological units to extract regularities takes place at the level of associative units. It is important to note that this level of associative units does not equate to the concept of “hidden units” in the connectionist model of reading acquisition (Seidenberg & McClelland, 1989). However, the connectionist model most closely aligns with our conception. Another method to investigate the level of associative units involves administering tasks with ambiguous stimuli, either at the orthographic level (e.g., the *illusory conjunction* paradigm) or the phonological level (e.g., phonological awareness tasks). The manner in which individuals respond to these task can shed light on the reorganisation of associations between orthographic and phonological representations at the level of associative units. The experiments detailed in Chapter 5 were designed to assess how participants’ responses on a syllable counting task are shaped by the interplay between orthographic and phonological representations, specifically

through reorganisation at the level of associative units, and to understand how this influence varies with literacy development.

On the role of statistical learning at the very beginning of learning to read

Experiments 4.1 and 4.2 in Chapter 4 aimed to examine whether letters-to-syllable associative learning could trigger statistical learning, enabling prereaders to detect and extract GPC regularities from this micro-orthographic environment. To achieve this aim, we trained French-speaking prereaders with eight letters-to-syllable associations, which embedded either eight GPC regularities (termed the “rich supply”) or four GPC regularities (termed the “poor supply”). We hypothesised that if statistical learning could be initiated through letters-to-syllable association learning, then the “rich supply” training group, which provides a more conducive orthographic environment, might exhibit stronger activation of statistical learning than the “poor supply”. This, in turn, could lead to better acquisition of GPC regularities, as assessed by phonemic awareness and the generalisation to nonlearned syllables.

The results from Experiment 4.1, involving prereaders with a low level of phonemic awareness as assessed in the pretests at regular preschools, confirmed this prediction. They showed that the “rich supply” training led to a greater increase in phonemic awareness than the “poor supply” training group. Experiment 4.2’s results, with prereaders from preschools in priority education networks, were also in line with this prediction. These prereaders, who already had a high level of phonemic awareness, generalised nonlearned syllables better when trained with the “rich supply” compared to the “poor supply”.

Our findings empirically demonstrated, for the first time, the potential role of statistical learning in extracting GPC regularities at the outset of learning to read. This involvement of statistical learning further underscores the viability of the “syllabic bridge”-based approach. The reorganisation of letters-to-syllable associative learning through statistical learning at the

level of associative units does not require learning an exhaustive list of syllables. A modest set of letters-to-syllable associations might be enough to trigger statistical learning, facilitating the assimilation of GPC regularities. This process would facilitate further the acquisition of the alphabetic principle.

On the influence of statistical orthographic knowledge on phonology

The aim of Chapter 5 was to explore the level of associative units by administering a syllable counting task that used acoustic pseudowords, where the number of syllables was ambiguous. The acoustic stimuli used in this task were designed based on general statistical orthographic properties. While they lacked defined spelling patterns, these patterns depended on the frequency with which their phonological rhymes appeared across the French lexicon. Specifically, the rhymes of the acoustic stimuli ranged from having a low to high probability of being spelled with a terminal “e”. If individuals are more inclined to perceive acoustic stimuli ending in a rhyme with a lower probability of being spelled with a terminal “e” (e.g., [kluf] ending in [-uf]) as monosyllabic, compared to those ending in a rhyme with a higher probability of being spelled with a terminal “e” (e.g., [spuʃ] ending in [-uʃ]), then this might suggest the existence of a finer level of associative units that underpin the relationship between orthography and phonology. Furthermore, if this effect of statistical orthographic knowledge is predominantly observed in individuals who are already readers, it could further suggest that the level of associative units emerges from the gradual establishment of orthographic-phonological associations.

The results from Experiment 5.1 aligned with the anticipated effects of statistical orthographic knowledge and the interaction between this knowledge and reading level. Generally, individuals were more inclined to perceive acoustic stimuli as monosyllabic for pseudowords ending in a rhyme with a higher probability of not being spelled with a terminal

“e” compared to pseudowords ending in a rhyme with a lower such likelihood. Furthermore, this influence of statistical orthographic knowledge became more pronounced as an individual’s reading level progressed. Specifically, this knowledge had a significant impact on syllable counting for participants at the 5th-grade and literate adult reading levels, but it was not significant at the 1st and 2nd-grade reading levels. Results from Experiment 5.2, which involved prereaders, indicated that the acoustic stimuli were consistently identified as monosyllabic. This suggests that the level of associative units has not yet formed in prereaders who have not been systematically exposed to orthographic-phonological associations.

Our findings suggest the potential existence of a level of associative units in cognitive representations that generate the relationship between orthography and phonology. Individuals’ responses to the counting of acoustic pseudowords, wherein the number of syllables is ambiguous, reflect an unconscious calculation based on statistical orthographic knowledge at this level of associative units. The formation of this system of associative units is a progressive process resulting from the cumulative learning of orthographic-phonological correspondences.

Theoretical implications

Explicit learning vs. statistical learning of GPC regularities

Our findings provide evidence, for the first time, of the potential involvement of statistical learning in acquiring GPC regularities. This discovery could challenge prevailing approaches to acquiring the alphabetic principle. We propose that introducing associative learning of correspondences between letter strings and phonological syllables could serve as a preparatory step. The potential involvement of statistical learning could enable children to extract GPC regularities, thereby facilitating the subsequent acquisition of the alphabetic principle through explicit instruction.

Some might argue that learning associations between letter strings and phonological syllables as a preparatory step is redundant, especially if most children ultimately acquire the alphabetic principle by directly learning GPCs, irrespective of the duration involved. However, can we genuinely claim that any child learns to read by grasping pure GPCs without ever being exposed to orthographic-phonological associations? The likely answer is no, considering that even phonics explicit instruction contains a “mnemonic” dimension, requiring children to memorise correspondences between letter strings and phonological patterns, as discussed in Chapter 2. In this light, the cornerstone of learning to read might be an orthographic environment encompassing orthographic-phonological associations, rather than an alphabetic system consisting solely of GPC regularities. This need of the orthographic environment is supported by two observations. Firstly, some precocious children seem to acquire the alphabetic principle simply through exposure to printed words that are read aloud without explicit instruction (e.g., Fletcher-Flinn, 2000; Fletcher-Flinn & Thompson, 2004; Thompson et al., 1996). Secondly, research on Korean literacy acquisition shows that Korean children learn to recognise simple syllabic characters by the age of four, and most can read words containing even more complex syllabic characters by the age of six, before starting primary school (Cho et al., 2009). Thus, it appears that both alphabetic and Korean precocious learners benefit from exposure to an orthographic environment to grasp the alphabetic or the Korean alphabetic principle.

Therefore, associative learning between letter strings and phonological syllables is crucial as it provides children with a conducive orthographic environment. However, this does not diminish the importance of explicit phonics instruction in reading. In essence, letters-to-syllable associative learning furnishes a conducive orthographic foundation, ensuring all children are equally prepared before they embark on formal phonics instruction.

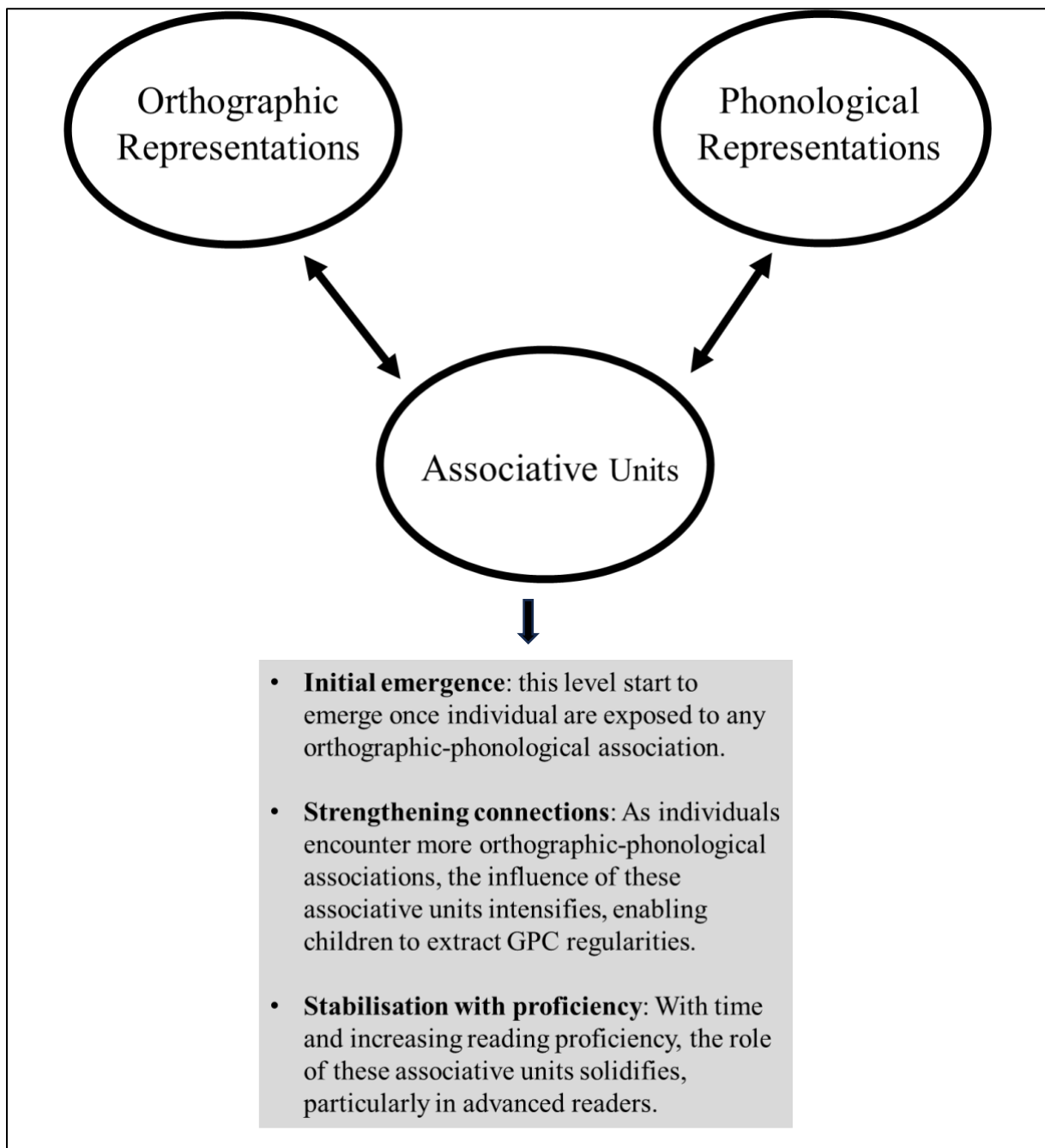
On the representation of the level of associative units

The cognitive system of writing embeds a network of associations between orthographic and phonological representations. One key feature in our theoretical framework is that these associations are not directly linked but are mediated by a level of associative units that stand between orthographic and phonological units. At first glance, these associative units appear similar to *hidden units* in the parallel distributed processing (PDP) model of visual word recognition and pronunciation (Seidenberg & McClelland, 1989). In the PDP model, both orthographic and phonological units, as well as the *hidden units*, exhibit *parallel distributed* properties. Specifically, the term “distributed” refers to the idea that knowledge is not stored in a single unit or location. Instead, information is spread across many units in the network. Each unit does not represent a specific piece of discrete knowledge by itself; rather, it is the pattern of activation across all the units that encodes the knowledge. The term *parallel* refers to the idea that many operations or processes happen simultaneously. Each unit in the network processes information at the same time as others, in parallel, allowing the model to rapidly respond to inputs. Although these properties have been illustrated through mathematical calculations and computational implementations, there have been no empirical studies offering a cognitive representation of these *hidden units*.

Our findings attempt, for the first time, to provide a mean to explore the cognitive representation of what we term *associative units* (see Figure 6.1). When individuals first encounter orthographic and phonological representations without clear connections between them, the *associative units* start to emerge. However, their role seems minor at this stage. This observation stems from Experiment 5.2 in Chapter 5. In this experiment, prereaders, who had not yet learned any syllables or words, relied solely on the acoustic characteristics of stimuli for a syllable counting task.

Figure 6.1

Cognitive representations of the level of associative units



As these individuals become more familiar with the links between orthographic and phonological forms, these associative units become stronger. As demonstrated in Experiments 4.1 and 4.2, this level might be bolstered by intensively learning a small set of letters-to-syllable associations, enabling children to implicitly detect and extract GPC regularities through

statistical learning. However, the rate at which these associative units form can vary according to individual differences. It is thus crucial to consider implementing interventions with optimal orthographic environment. This ensures that children can amplify the activation of statistical learning at the level of associative units.

Over time, and with increased literacy, the role and stability of these associative units solidify. This is particularly evident from the results of Experiment 5.2 in Chapter 5. The influence of statistical orthographic knowledge becomes more pronounced as reading proficiency improves, with the most significant impact observed in adult readers. These results suggest a gradual yet definite path towards establishing a well-integrated orthographic-phonological system. As individuals reach this comprehensive understanding, the role and influence of the associative units might stabilise.

Limitations and future directions

Experiments 4.1 and 4.2 assessed the progression toward the alphabetic code through the improvement of phonemic awareness and the generation of nonlearned syllables, respectively. It has been robustly established that phonemic awareness is one of the strongest predictors of literacy (e.g., Castles & Coltheart, 2004) and can be considered as an indicator of the preliminary mastery of the alphabetic principle. The generalisation of non-learned syllables is even stronger evidence of the generalisation of GPC regularities. However, our findings lack direct evidence of how learning the association between syllables and letters at the very beginning of learning to read helps children facilitate the alphabetic principle later and become better readers in the long term. In this case, a longitudinal study is needed to clarify this aspect. Specifically, in our conception, learning letters-to-syllables correspondences before learning the code (during the last year of kindergarten) will trigger the statistical learning mechanism and help children acquire the alphabetic principle when its explicit learning starts. To verify this

potential positive effect on reading, a follow-up strategy, testing children from kindergarten to primary school, is needed in the future.

Furthermore, another limitation of our findings is the lack of exploration of the interplay between explicit instruction and statistical learning. It is undisputed that explicit instruction plays a key role in reading acquisition. Our findings included explicit instruction but focused on its *mnemonic* aspect that requires children to memorise associations. However, the manner in which both the *explicative* and *mnemonic* dimensions of explicit instruction interact with statistical learning remains unclear. In our conception, the *mnemonic* dimension of explicit instruction is first provided to create a conducive orthographic environment for statistical learning, followed by the *explicative* dimension of explicit instruction. Are there other more effective sequences for arranging explicit instruction and statistical learning? A more thorough exploration of the interplay between explicit instruction and statistical learning is needed in future research.

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Appendices

Appendix A

Overview of the classification of the world's writings systems

| Linguistic Units | Writing Typology | Gelb (1952; 1963) | Hill (1967) | Sampson (1985) | De Francis (1989) | Daniels (1996) |
|------------------|----------------------------------|---|---------------------------------|--------------------------------|----------------------|---------------------|
| Morpheme | Word-Syllabic | Sumerian Egyptian Chinese | Sumerian Egyptian Chinese | | | |
| | Morphemic | | | Chinese | | |
| Syllable | Morpho-Syllabic Logosyllabary | | | | Sumerian Chinese | Sumerian Chinese |
| | Syllabic | Phoenician Hebrew Japanese | | Kana | | |
| | Pure Syllabic | | | | Kana, Yi | Kana |
| | Polyphonemic | | Kana | | | |
| | Partial-Phonemic | | Egyptian Hebrew | | | |
| | Abjad | | | | | Arabic |
| | Consonantal | | | Phoenician Hebrew Arabic | | |
| | Morpho-Consonantal | | | | Egyptian | |
| | Pure Consonantal | | | | Phoenician Hebrew | |
| | Abugida | | | | | Indic scripts |
| Phoneme | Alphabetic | Greek Hebrew (vocalised) Indic scripts | | | | Greek English |
| | Phonemic alphabets | | Greek Finnish | | | |
| Phonemic Feature | Pure Phonemic | | | | Greek Finish | |
| | Vocalic + Consonantal | | | Greek English French | | |
| | Morpho-Phonemic alphabets | | | | English, Korean | |
| | Morpho-Phonemic | | English, Korean | | | |
| | Featural | | | Korean | | Korean |

Appendix B

Different sets of letter-to-syllable associations allowing the extraction of varying amounts of GPC regularities, ranging from eight to four GPC regularities

| | A | I | O | U | |
|----------|---------|---------|---------|---------|--------|
| B | BA-/ba/ | BI-/bi/ | | | →B-/b/ |
| F | FA-/fa/ | FI-/fi/ | | | →F-/f/ |
| T | | | TO-/to/ | TU-/ty/ | →T-/t/ |
| S | | | SO-/so/ | SU-/sy/ | →S-/s/ |
| | ↓ | ↓ | ↓ | ↓ | |
| | A-/a/ | I-/i/ | O-/o/ | U-/y/ | |

| | A | I | O | U | |
|----------|---------|---------|---------|---------|--------|
| B | BA-/ba/ | BI-/bi/ | | BU-/by/ | →B-/b/ |
| F | FA-/fa/ | FI-/fi/ | | | →F-/f/ |
| T | | | TO-/to/ | | |
| S | | | SO-/so/ | SU-/sy/ | →S-/s/ |
| | ↓ | ↓ | ↓ | ↓ | |
| | A-/a/ | I-/i/ | O-/o/ | U-/y/ | |

| | A | I | O | U | |
|----------|---------|---------|---------|---------|--------|
| B | BA-/ba/ | BI-/bi/ | BO-/bo/ | BU-/by/ | →B-/b/ |
| F | FA-/fa/ | FI-/fi/ | | | →F-/f/ |
| T | | | TO-/to/ | | |
| S | | | | SU-/sy/ | |
| | ↓ | ↓ | ↓ | ↓ | |
| | A-/a/ | I-/i/ | O-/o/ | U-/y/ | |

| | A | I | O | U | |
|----------|---------|---------|---------|---------|--------|
| B | BA-/ba/ | BI-/bi/ | | | →B-/b/ |
| F | FA-/fa/ | FI-/fi/ | | | →F-/f/ |
| T | TA-/ta/ | TI-/ti/ | TO-/to/ | | →T-/t/ |
| S | | | | SU-/sy/ | |
| | ↓ | ↓ | | | |
| | A-/a/ | I-/i/ | | | |

| | A | I | O | U | |
|----------|----|----|-------|-------|--------|
| B | BA | BI | BO | BU | →B-/b/ |
| F | | | FO | FU | →F-/f/ |
| T | | | | TU | |
| S | | | | SU | |
| | | | ↓ | ↓ | |
| | | | O-/o/ | U-/y/ | |

Appendix C

Test form completed by the experimenter in the pretest in Experiments 4.1 and 4.2

NOM : _____ Prénom : _____ Classe : _____ **Pré-test Octobre 2022**

N° : _____

Date et heure : _____

Expérimentateur : _____

Les informations suivantes seront récoltées :

Date de naissance _____ **Genre** fille garçon

Lunettes oui non

Latéralité droitier/ère gaucher/ère

Français parlé à la maison : oui non **Sinon** : _____

Profession des parents : père _____ mère _____

PRETEST

PRETEST - NOM DES LETTRES Ordre fixe ; Règle d'arrêt : aucune.

Consigne voyelles : « voici une lettre, tu connais son nom ? »

Consigne consonnes : faire 2 exemples : M → /m/ et R → /r/ ; 1 entraînement M → /m/

Consigne 1 : « voici une lettre, tu connais son nom ? »

Puis consigne 2 : « Tu peux me dire le son qu'elle fait quand elle commence un mot, quand on la lit ? »

| Item | Réponse | Score voyelle | Item | Réponse nom | Score nom | Réponse son | Score son | |
|---------|---------|---------------|---------|-------------|-----------|-------------|-----------|----|
| A | | | B | | | | | |
| I | | | F | | | | | |
| O | | | T | | | | | |
| U | | | S | | | | | |
| Score : | | /4 | Score : | | /4 | Score : | | /4 |

PRETEST - LECTURE DE SYLLABES Ordre fixe ; Règle d'arrêt : aucune

Consigne : « voici un morceau de mot, tu peux le lire ? »

| Item | Réponse | Score | Item | Réponse | Score | |
|---------|---------|-------|---------|---------|-------|------------|
| BA | | | TO | | | |
| BI | | | TU | | | |
| FA | | | SO | | | |
| FI | | | SU | | | |
| Score : | | /4 | Score : | | /4 | Total : /8 |

PRETEST - LECTURE DE SYLLABES Ordre fixe ; Règle d'arrêt : aucune

Consigne : « voici un morceau de mot, tu peux le lire ? »

| Item | Réponse | Score | Item | Réponse | Score | |
|---------|---------|-------|---------|---------|-------|------------|
| BO | | | TA | | | |
| BU | | | TI | | | |
| FO | | | SA | | | |
| FU | | | SI | | | |
| Score : | | /4 | Score : | | /4 | Total : /8 |

NOM : _____ Prénom : _____ Classe : _____ **Pré-test Octobre 2022**

PRETEST - SUPPRESSION DE PHONEME FINAL Ordre fixe ; Règle d'arrêt : après 4 échecs consécutifs pour le bloc 1 et après 2 échecs consécutifs pour les blocs 2 et 3.

1 exemple (avec TAR) et 2 entraînements (avec DUK et LOB). ATTENTION : pour les items contenant O, le prononcer /o/ et pas /ɔ/. Consigne : « Qu'est-ce qui reste si tu enlèves le petit morceau à la fin de... »

BLOC 1

| Item | Réponse juste | Erreur | Score | Item | Réponse juste | Erreur | Score |
|------|---------------|--------|-------|------|---------------|---------|-------|
| BAC | ba | | | FIP | fi | | |
| BIT | bi | | | SOL | so | | |
| TUP | tu | | | FAT | fa | | |
| TOL | to | | | SUK | su | | |
| | | | | | | Score : | /8 |

BLOC 2

| Item | Réponse juste | Erreur | Score | Item | Réponse juste | Erreur | Score |
|------|---------------|--------|-------|------|---------------|---------|-------|
| BUL | bu | | | SAP | sa | | |
| BOC | bo | | | FUT | fu | | |
| TAL | ta | | | SIL | si | | |
| TIP | ti | | | FOK | fo | | |
| | | | | | | Score : | /8 |

BLOC 3

| Item | Réponse juste | Erreur | Score | Item | Réponse juste | Erreur | Score |
|------|---------------|--------|-------|------|---------------|---------|-------|
| VIP | vi | | | MOT | mo | | |
| VUC | vu | | | MUL | mu | | |
| PAT | pa | | | RAP | ra | | |
| POL | po | | | RIC | ri | | |
| | | | | | | Score : | /8 |

Note. The pretest form was the same for all groups. The posttest form was the same as that of the pretest, with the order of items changed in the syllable reading task and final phoneme deletion task according to the groups.

Appendix D

Forty phonetic forms of the pseudowords of the set A in Experiment 5.1

| Phonetic forms ending in /b/ | Phonetic forms ending in /d/ | Phonetic forms ending in /g/ |
|------------------------------|------------------------------|------------------------------|
| [bãb] | [flud] | [jẽg] |
| [bɤab] | [fɔd] | [klẽg] |
| [fɤãb] | [kɤyd] | [fag] |
| [glab] | [dɤɔd] | [flɔg] |
| [klɔb] | [pud] | [glig] |
| [fɔb] | [gɤud] | [nag] |
| [psab] | [plɔd] | [plẽg] |
| [skab] | [plyd] | [slɔg] |
| [skãb] | [skɔd] | [spig] |
| [plãb] | [stud] | [spẽg] |
| [spɔb] | [styd] | [stag] |
| [tɤɔb] | [vyd] | [tɤag] |
| | | [spɔg] |
| | | [tig] |
| | | [vɤig] |
| | | [zɔg] |

Appendix E

Forty phonetic forms of the pseudowords of the set B in Experiments 5.1 and 5.2

| [ys] | [ɛf] | [us] | [is] | [uf] |
|---------|--------|--------|--------|--------|
| [klys] | [blɛf] | [klus] | [blis] | [bɤuf] |
| [fɤys] | [kɤɛf] | [dɤus] | [gɤis] | [kluf] |
| [skɤys] | [glɛf] | [plus] | [skis] | [gɤuf] |
| [snys] | [psɛf] | [slus] | [vɤis] | [tɤuf] |
| [ãj] | [ãs] | [yj] | [ij] | [uj] |
| [kãj] | [dɤãs] | [gɤyj] | [flij] | [fuj] |
| [fãj] | [glãs] | [pɤyj] | [gɤij] | [spuj] |
| [stãj] | [psãs] | [slyj] | [stij] | [tɤuj] |
| [dɤãj] | [spãs] | [tlyj] | [vɤij] | [vuuj] |

Appendix F

Six trials in the training block in Experiment 5.1

| Phonetic forms |
|----------------|
| [mlo] |
| [ʃla] |
| [blo] |
| [zoti] |
| [valto] |
| [kʷigu] |

Appendix G

Forty fillers used in Experiment 5.1 (20 bisyllables, 20 monosyllables)

| Bisyllables | Monosyllables |
|-------------|---------------|
| [pito] | [mʷi] |
| [paty] | [kli] |
| [tipa] | [spo] |
| [katy] | [sfi] |
| [klõpi] | [vʷo] |
| [vuke] | [zba] |
| [medu] | [ʒẽ] |
| [miʷlẽ] | [tly] |
| [bidã] | [sto] |
| [bʷly] | [dlo] |
| [bylni] | [ksa] |
| [dopiʷ] | [ʃʷu] |
| [dygã] | [sly] |
| [gʷazo] | [zlõ] |
| [guʃi] | [mʷa] |
| [niʃy] | [ʷaj] |
| [nefo] | [tli] |
| [fozy] | [ʷij] |
| [sopy] | [sla] |
| [sakõ] | [vzo] |

Appendix H

Twenty Fillers Used in the Experiment 5.2 (10 bisyllables, 10 monosyllables)

| Bisyllables | Monosyllables |
|-------------|---------------|
| [paty] | [kli] |
| [katy] | [spo] |
| [klõpi] | [vɤo] |
| [medu] | [sto] |
| [miɤlẽ] | [dlo] |
| [bidã] | [ksa] |
| [bɔɤly] | [ʃɤu] |
| [bylni] | [tli] |
| [niʃy] | [ɥij] |
| [nefo] | [sla] |