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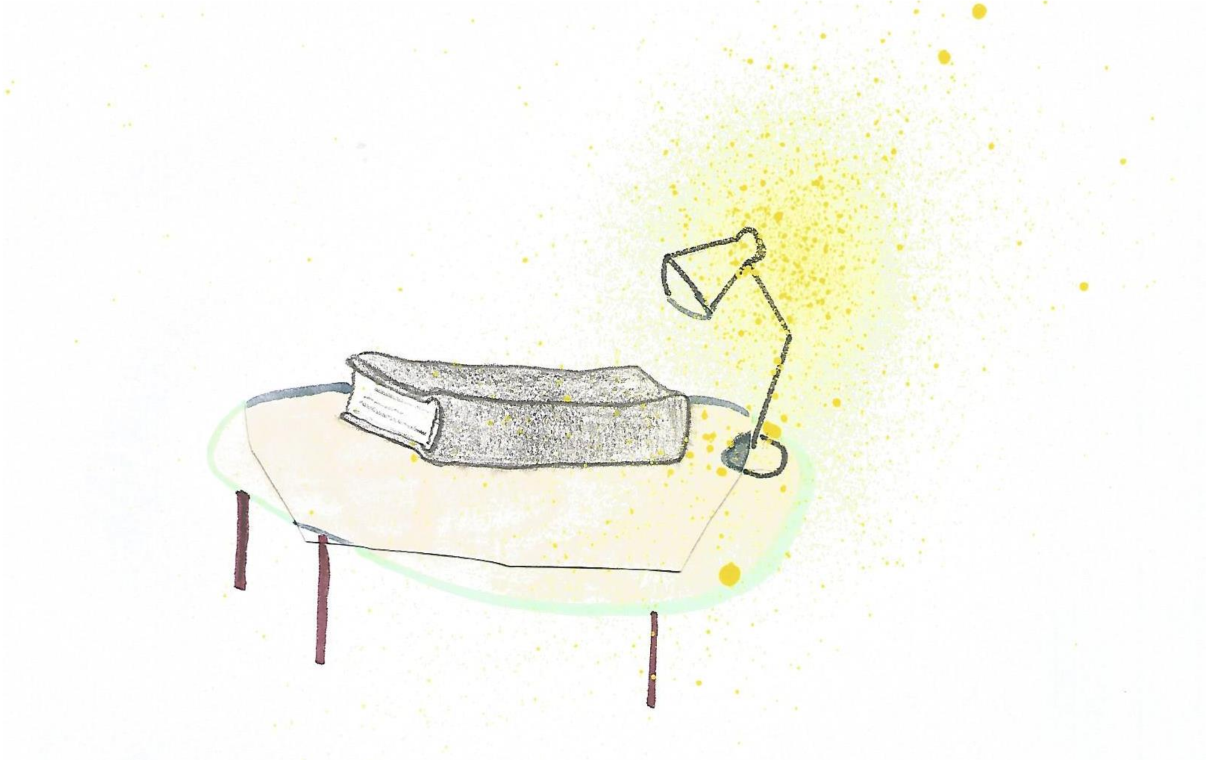

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The visual attention span as a measure of orthographic grain size: effects of orthographic depth and morphological complexity.

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BCBL Basque Center on Cognition, Brain and Language
Paseo Mikeletegi, 69,
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Abstract

When reading, the size of the orthographic and thus phonological units (or grains) that one is able to process efficiently depends on a number of factors, for example the individual's reading expertise (Ehri, 2005) and the familiarity of the encountered word(s) (Grainger & Ziegler, 2011). Both factors are related to whether the individual can link the orthographic units of the word to its orthographic and subsequently phonological and semantic representations in the lexicon. The mappings between lexical and sub-lexical orthographic grains at the semantic/morphological and phonological level can influence the size of the orthographic and phonological grains used in reading. For example, many studies have highlighted how readers of deeper orthographies, in which grapheme-to-phoneme mappings are more complex and/or less consistent, tend to rely on larger grains in reading (Ziegler & Goswami, 2005). The main goal of this thesis was to specifically study the modulation of *orthographic* grain size in reading, focusing on the visual aspects of orthographic processing and using the visual attention span (Bosse, Tainturier, & Valdois, 2007) as an indirect measure of orthographic grain size in reading. In particular, we studied the effect of a language's orthographic depth and morphological characteristics on orthographic grain size with two cross-linguistic studies (in readers of Basque, Spanish and French), and the effect of morphological structure at the word level (morphological complexity) on orthographic grain size with two studies in Basque. Three of our studies focused on developing readers (the fourth was in skilled adult readers), and two of these were cross-sectional including readers in the first two years of formal literacy instruction and more advanced readers. Our results provided support for the modulation of orthographic grain size based on orthographic depth, language morphology and morphological complexity, and for the adequacy of the VA span as a measure of orthographic grain size. More specifically, our results indicated that larger orthographic grains, and thus higher visual attention span demands were, in the cross-linguistic studies, linked to reading in an orthography with more complex grapheme-to-phoneme mappings and possibly to reading in an agglutinative language. In the within-language studies in Basque, our results showed that using larger orthographic grains and thus higher visual attention span demands were associated to the presence of less semantic (morphological) information at the sub-lexical level. Finally, our results also showed that both cross-linguistic and within-language differences in orthographic grain size could only be observed after a certain degree of reading expertise was attained (i.e., not in readers in the first years of formal literacy instruction). Overall, the present thesis suggests a new perspective through which to study the visual demands and limitations imposed on orthographic processing during reading development in alphabetic orthographies.

Contents

Part I

Introduction

Chapter 1

Conceptual Background

Every reader is faced with the task of identifying written words on a daily basis. The process through which this is achieved can differ greatly. On the one hand, adult skilled readers barely notice how, while walking down a street, information about street names, bank loan conditions, supermarket offers and upcoming concerts seeps into their conscience. On the other hand, children who are on the threshold of literacy cannot perform this task effortlessly, sometimes coming to a complete halt in the middle of the street in order to slowly and steadily read words that have caught their attention. This illustrates that words are more likely to be processed as a whole (a process referred to as lexical or sight word reading) by more skilled readers, whose efficient orthographic processing skills have been fine tuned with the support of their linguistic and visual processing abilities. For less skilled readers or for unfamiliar words, it is necessary to decompose the word into smaller orthographic units or grains in order for it to be read correctly. The size of the orthographic grains into which a word will be decomposed if it cannot be processed as a whole depends on the aforementioned factors (e.g., reading skill and visual/orthographic processing capacity), but could also be influenced by additional factors such as the manner in which the word's constituent orthographic grains map onto sounds (phonology) and meaning (semantics). ***The present work*** aims to identify how the size of the orthographic grains that map onto single linguistic units of sound (phonemes) or meaning (morphemes) and the consistency of these mappings can interact with visual and orthographic processing in readers of varying skill.

1.1 The modulation of orthographic grain size

1.1.1 Lexical reading and orthographic grain size as function of reading skill and word familiarity

Research on reading in alphabetic orthographies has described how the reader evolves from requiring a large amount of cognitive resources to read a single word, to performing this task almost effortlessly. This transition is based on the reader mastering the mappings of single and multi-letter graphemes onto phonological representations, which subsequently permits the acquisition of a large inventory of lexical orthographic representations. Repeated exposure to words whose lexical orthographic representations have been acquired (i.e., familiar words) finally results in their efficient and effortless processing. This allows the reader to reallocate cognitive resources to higher level processing mechanisms (e.g., text level reading comprehension, Verhoeven & Perfetti, 2017).

Theories of reading development have provided a detailed description of the stages through which the reader transitions, gradually increasing her/his ability to read words and to process larger orthographic grains (for one example, see figure 1.1). Early on and before receiving formal reading instruction, individuals are unaware of grapheme-to-phoneme mappings and thus have yet to develop orthographic processing skills. Nevertheless some children can identify a limited amount of words solely based on visual cues (e.g., identifying the word “look” based on the two “o”s that look like eyes in the center of the word), and with little attention to detail (e.g., easily confusing “look” and “book”: the pre-alphabetic phase: Ehri, 1995, 2005; Ehri & McCormick, 1998 or logographic stage: Frith, 1985). At the beginning of reading instruction, the foundation for the development of orthographic processing skills is provided by the gradual acquisition of grapheme-to-phoneme mappings. Some of these mappings are acquired earlier on than others, allowing children to identify certain short words and start adding them to their orthographic inventory (partial alphabetic phase: Ehri, 2005). When all grapheme-to-phoneme mappings have been acquired (full alphabetic phase: Ehri, 2005 or alphabetic stage: Frith, 1985, the latter encompasses both the partial and full alphabetic phases), orthographic processing skills increase substantially and concurrently with children’s increased rate of adding words to their orthographic inventory. The increase in the inventory of lexical orthographic representations subsequently allows readers to ***process more words at sight***.

At the same time, ***readers become capable of processing larger orthographic grains in unfamiliar words, as a result of fine tuning their orthographic***

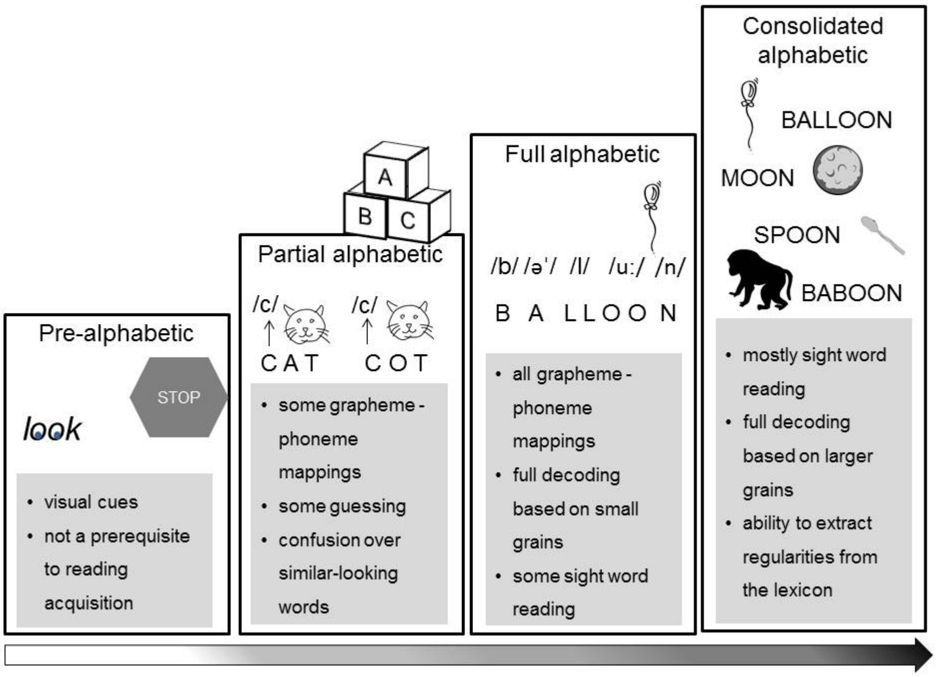

Figure 1.1: Ehri's phases of word reading development

processing skills to the regularities of the orthography. This is achieved due to the extraction of statistical information/rules from the acquired inventory of lexical representations, which provides the reader with increased sensitivity to the orthographic patterns of syllables, rimes and morphemes (consolidated alphabetic phase: Ehri, 2005 or orthographic phase: Frith, 1985). Thus at this final stage of development both small and larger orthographic grains are accessible to the reader who can process unfamiliar words using either sequential decoding, analogy (mapping larger orthographic grains of an unfamiliar word to those of a familiar word), or prediction (relying on letter cues and context to predict pronunciation: Ehri, 1992, 2005). This is also in line with the self-teaching hypothesis (Share, 1995, 1999), an alternative theory of reading development according to which reading develops in a continuous manner, with sight word reading being available for some words from early on (and for increasingly more words as reading experience increases) and unfamiliar words always being subject to the process of phonological recoding (Jorm & Share, 1983). According to this theory the reader can acquire new entries for her/his orthographic lexicon based on the phonological recoding of unfamiliar written words if these words are part of the spoken vocabulary. Similarly to what is postulated by stage theories of reading acquisition (Ehri, 1992, 2005; Frith, 1985), for the inexperienced reader phonological recoding would be based on sequential decoding of letters, while as reading experience increases, the increase in the knowledge of grapheme-to-phoneme mappings, in phonological sensitivity, and in the ability to use contextual information to determine pronunciation, would allow the reader to perform recoding based on larger orthographic grains.

Based on the aforementioned accounts of reading development we would expect ***models of skilled reading*** to reflect two aspects of expert reading: the ability to read familiar words by sight and, the ability to decode unfamiliar words based on the use of multi-letter sub-lexical orthographic grains when they are the most salient/efficient reading unit (as is the case for multi-letter graphemes, syllables or rimes). Models of skilled reading have taken two main approaches to implementing these processes, either using a computationally distinct mechanism for familiar as opposed to unfamiliar word reading (dual-route models), or implementing both within a single connectionist network.

The Dual Route Cascaded (DRC) model is an example of a dual-route model of reading (Coltheart & Rastle, 1994; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), postulating that familiar and unfamiliar words are processed through two distinct and parallel routes: lexical and non-lexical. ***For familiar words, the lexical route is usually faster***, since it involves the activation of a single unit representation of the word in the phonological and then the orthographic lexicon, ***in line with the expectation that familiar words should be read efficiently through sight word reading***. For unfamiliar words, processing relies on serial decoding based on a predefined set of rules (grapheme-to-phoneme correspondence rules, GPC). Therefore, information from the lexical route, and thus the orthographic lexicon, does not influence the non-lexical route meaning unfamiliar words can only be read correctly if they can be correctly decoded based on grapheme-to-phoneme mappings[1]. This means that according to this model the size of the sub-lexical orthographic grains that are available to the reader coincide with the size of the graphemes and cannot be modulated by other factors. The DRC model accounts for the dissociation between surface and phonological dyslexia representing the former as damage to the lexical and the latter as damage to the non-lexical route, thus reflecting the dissociation in the difficulty reading words as opposed to non-words and vice versa in these two types of developmental reading disorder (for an

[1]Multiple level models (Norris, 1994; Shallice & McCarthy, 1985) provide one example of dual route models that implement reading unfamiliar words by analogy (suggested to play a role in word reading: Glushko, 1979). This is achieved with the inclusion of a larger variety of grapheme-to-phoneme mappings in the non-lexical route, spanning from single letter graphemes, to multi-letter graphemes, to larger orthographic units, morphemes and finally whole words.

implementation of self-teaching within the DRC model see: Pritchard, Coltheart, Marinus, & Castles, 2018).

The triangle models are the main opponents of the DRC model of skilled reading (Harm & Seidenberg, 2004; McClelland, Rumelhart, & Hinton, 1986; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) and are connectionist models that use the same computational mechanism to implement familiar and unfamiliar word reading. Their name reflects that they are composed of three main layers of interconnected units representing orthography, phonology and semantics. They constitute PDP models because: a) activation spreads in *parallel* across layers and b) representations are *distributed* across a number of units (e.g., the orthographic representation of a word is distributed across a number of connected units in the orthographic layer). Importantly, triangle models do not require a predefined set of grapheme-to-phoneme mapping rules, but can learn them through exposure to written words and their correct spoken forms. The same process allows the models to capture statistical regularities between orthography-phonology and orthography-semantics-phonology mappings at the sub-lexical level (Harm & Seidenberg, 2004), ***allowing the processing of unfamiliar words based on larger orthographic grains, such as syllables, rimes and even morphemes***. Regarding the implementation of developmental reading disorders, triangle models also dissociate surface and phonological dyslexia based on a disruption in the semantic (Plaut et al., 1996; Welbourne & Lambon Ralph, 2007; Woollams, Hoffman, Roberts, Lambon Ralph, & Patterson, 2014) or the phonological layer respectively (Harm & Seidenberg, 2001). Overall, while the DRC model has been more successful in modelling human performance than triangle models, the ability to adjust the rules and lexicon of the DRC model in order to accommodate each dataset disputes its superiority (for two opposing views: Coltheart, 2006; Seidenberg & Plaut, 2006).

Key points

This section provided an overview of how readers might develop: a) the ability to rapidly process familiar words as a whole, and b) the ability to rely on smaller or larger sub-lexical orthographic grains to process unfamiliar words. Even from this brief introduction it becomes clear that linguistic skills overall (such as vocabulary knowledge that supports the direct mapping of the whole word orthographic onto the whole word phonological representation), and phonological skills more specifically (that support the acquisition of grapheme-to-phoneme mappings), are paramount to reading development. The following section will introduce the idea that ***visual processing skills*** could also influence reading (e.g., Grainger, Dufau, &

Ziegler, 2016; Rayner, 2009; Vidyasagar & Pammer, 2010) . More specifically, now that a broad description of how ***orthographic grain size is modulated by word familiarity and reading skill*** has been given, the following section will provide more information on ***the visual and orthographic processing demands of reading*** and how they interact with familiar and unfamiliar word processing and the use of smaller or larger orthographic grains.

1.1.2 Orthographic and visual processing in reading: modulation based on reading route and orthographic grain size

The previously presented models of skilled reading inspired researchers to combine the strengths of dual-route and connectionist approaches based on the principle of nested incremental modelling[2] (Jacobs & Grainger, 1994). One representative of this type of models is the connectionist dual process (CDP) model and its successors (Perry, Ziegler, & Zorzi, 2007, 2010, 2013, 2014; Zorzi, Houghton, & Butterworth, 1998). An important aspect of these models is that they implement a separate lexical route (similarly to the DRC model and based on a lexical network) for familiar word processing, and a sub-lexical route (based on a connectionist neural network that is also used in triangle models) for unfamiliar word processing (Zorzi et al., 1998, see figure 1.2). Thus, ***the models separate the mechanisms underlying familiar and unfamiliar word processing but also allow the reader to rely on larger orthographic grains in the sub-lexical processing of unfamiliar words***. More specifically for unfamiliar words, the orthographic input is processed through a two-layer network of phonological assembly that, unlike the non-lexical route of the DRC model, implements learning of statistically reliable orthography to phonology mappings and produces the phonological output. Moreover, in CDP models the written word is processed based on visual feature detectors that lead to position-specific letter activation, providing a more concrete implementation of ***visual aspects of orthographic processing***.

Theoretically, it has also been suggested that at the level of orthographic processing the combination of the strengths of connectionist and dual route models is optimal, since it would allow two separate routes for lexical and sub-lexical reading,

[2]Some examples of these nested or hybrid models are the MROM-p interactive activation multiple read-out model (Jacobs, Rey, Ziegler, & Grainger, 1998), and the bi-modal interactive-activation-BIAM model (Diependaele, Ziegler, & Grainger, 2010).

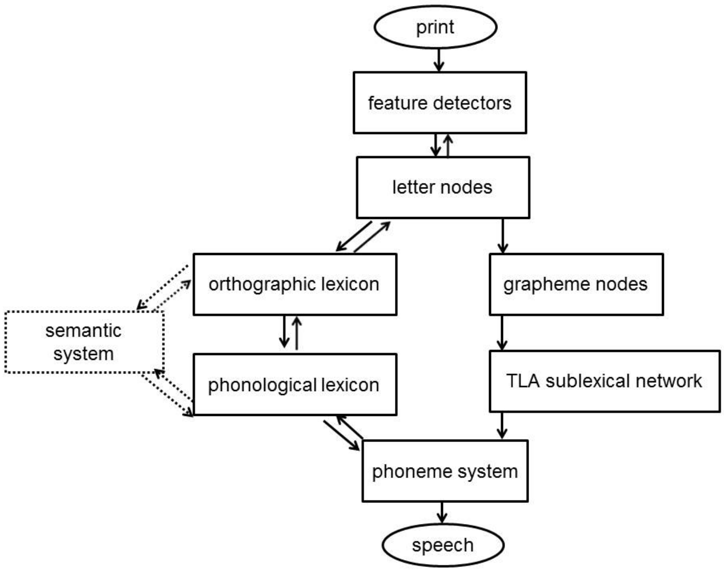

Figure 1.2: The CDP+ model of reading, a basic representation. Adapted from Perry et al. (2007) and Timmer and Schiller (2014). The dashed lines represent the section of the model that was not implemented.

thus adapting orthographic and visual demands to lexical reading and/or the size of the orthographic grain. This would allow reading to be maximally efficient, since different orthographic constraints could be placed on the processing of familiar and unfamiliar words (Grainger & Ziegler, 2011, see figure 1.3). Lexical reading should be based on ***coarse grain*** orthographic processing, primarily constrained by diagnosticity. Diagnosticity optimizes the processing of the orthographic input by aiming to process letter identity and approximate letter position of the minimal number of letters that allow the identification of the word (i.e., the activation of the correct orthographic representation). Unfamiliar word reading requires ***fine grain*** orthographic processing that is defined by the chunking constraint, allowing the identification of ***salient orthographic grains***. Salient orthographic grains can be those corresponding to known phonological/semantic representations: an example at the level of orthography to phonology mappings is the orthographic grain "air" in the word "chair", and at the level of orthography to semantics mappings is the orthographic grain "er" in "farmer" (see subfigures a and b of figure 1.3 respectively). Fine grain processing differs from coarse grain processing in that it requires precise letter identity and letter position coding. ***Since orthographic processing when reading provides the "central interface" mediating information exchange between visual and linguistic processing (Grainger, 2017) it is likely that the constraints on orthographic processing related to word familiarity and orthographic grain size could modulate and be modulated by visual and***

linguistic demands/resources. For example higher demands on orthographic processing could result in higher demands on visual processing. On the other hand, a reader's higher amount of either visual or linguistic resources should both facilitate orthographic processing.

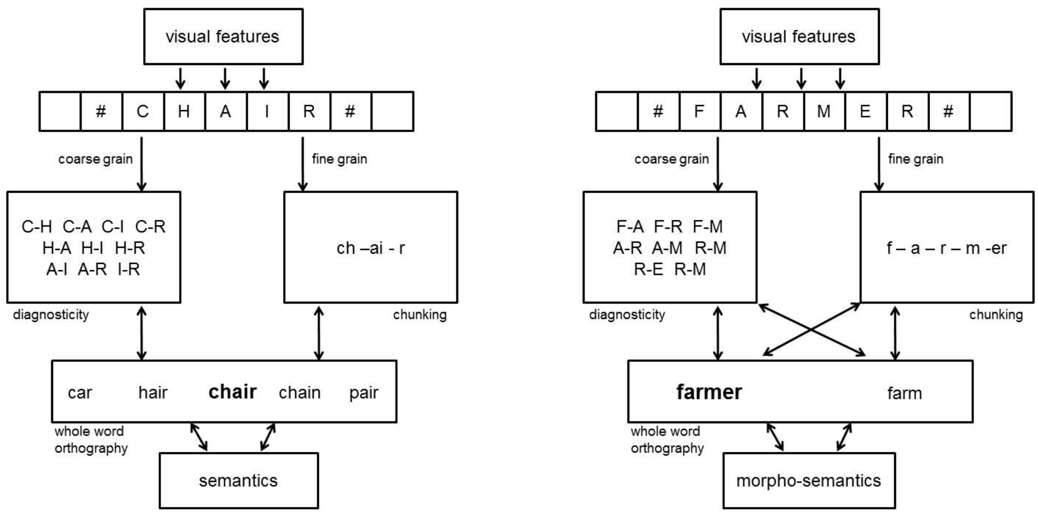

Figure 1.3: A dual route for orthographic processing, adapted from Grainger and Ziegler (2011). Subfigure (a) shows how this theoretical framework accounts for the processing of a word that sub-lexically includes regularities at the level of orthography to phonology mappings. Subfigure (b) shows how the theoretical framework also accounts for the processing of a word that sub-lexically includes regularities both at the level of orthography to phonology, and at the level of orthography to semantics.

The CDP models are one example of models combining ***a dual route approach to word reading*** that includes ***the benefits of connectionism in the implementation of learning and the ability to represent both smaller and larger sub-lexical orthographic grains***. Moreover, the dual route theory of orthographic processing provides a framework in which the conceptualization of these two different routes is essential since ***orthographic processing may involve different visuo-attentional constraints when reading familiar as opposed to unfamiliar words***. In the next paragraphs we will present another model that manages to reconcile the implementation of two routes in reading and a connectionist framework. The most critical aspect of this model is that ***it implements the aspect of visual attention in reading***.

The multiple trace model (MTM) model of polysyllabic word reading (Ans, Carbonnel, & Valdois, 1998) is a connectionist model of skilled reading that, similarly to PDP and CDP models, is able to extract grapheme-to-phoneme conversion rules and orthographic regularities based on exposure to orthographic and phonological representations of whole words and their syllables. In contrast to all the previously discussed dual route models, the MTM implements two routes; one for the processing of familiar words (global route-similar to lexical) that always takes precedence over the route of processing unfamiliar words (analytic-similar to non-lexical). Crucially, both routes are based on the same computational principles and the only parameter that changes when processing a familiar as opposed to an unfamiliar word is the visuo-attentional component of the model which defines ***the amount of information that can be processed simultaneously from the orthographic input: the reader's window of visual attention***.

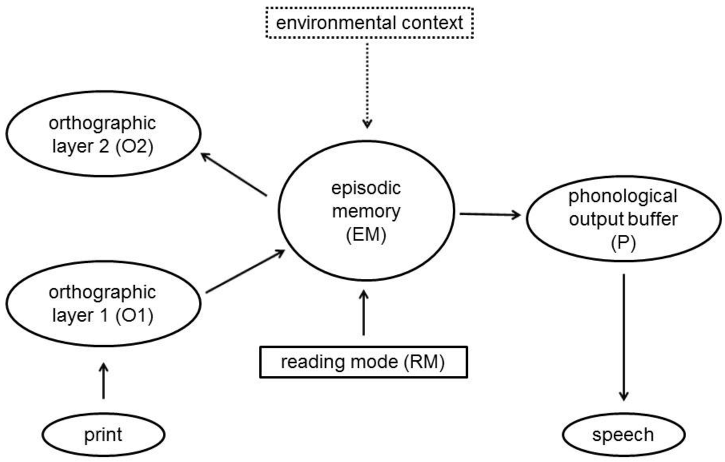

Figure 1.4: The MTM model of reading, a basic representation. Adapted from Ans et al. (1998). The dashed lines represent the section of the model that was not implemented.

In the MTM model, reading aloud begins with the recognition of individual letters directly, based on the position at which they are presented (i.e., without an intermediate step of activation of particular visual features). Therefore it does not account for aspects of letter identity and letter position coding during orthographic processing. Initially, the window of the reader's visual attention is always set to process the input globally[3] with parallel processing of all the letters, thus allowing

[3]Although the authors suggest that in order to simulate human performance under certain conditions,

efficient sight word reading. The larger the reader's window of visual attention is, the more likely it is for the global route to be successful in processing a familiar word, thus creating a word trace in episodic memory and making its orthographic representation more robust. If the reader's window of visual attention is not large enough to process all the letters of a word in parallel, or if the word is unfamiliar (i.e., lacking a lexical orthographic representation in the model), then the window of attention switches to analytic mode and reduces its size in order to decode the orthographic input based on smaller orthographic grains, such as single or multi-letter sub-lexical units (typically the syllable). ***A larger window of visual attention also allows the reader to be more efficient at identifying larger orthographic grains sub-lexically*** (in analytic mode), since with a larger window of visual attention traces of larger sub-lexical units are created in episodic memory and lead to the formation of their orthographic representations. As a result this increases the likelihood of processing salient orthographic units. According to this model, ***a large window of visual attention is critical in global processing, since it foments the formation of robust lexical orthographic representations*** that depend upon processing the word as a whole. Although the analytic mode also contributes to the development of orthographic knowledge and its efficiency depends on the size of the window of visual attention (also see: Valdois et al., 2006), phonological skills are of particular relevance in processing unfamiliar words that are processed sub-lexically. Accordingly, the MTM model accounts for surface dyslexia based on a deficit in the window of visual attention that principally affects the global mode, and for phonological dyslexia based on a deficit in phonological processing that affects the analytic mode.

Key points

This section highlighted that the mechanisms involved in word reading are related to ***specific demands on visuo-attentional resources***, and that these demands may be influenced by the processing ***route (lexical or sub-lexical)*** and by ***orthographic grain size (coarse or fine)***. Notably it highlighted that the window of visual attention can define whether reading is lexical or sub-lexical, that it can modulate the available orthographic grain size, and that it can support the formation of robust lexical orthographic representations (thus supporting fluent sight reading). The next section will focus on the counterpart of the reader's window of visual attention at the neuropsychological (human)

such as reading a list of pseudowords, one could consider that reading would default to analytic mode (as a result of the environmental context).

level, ***the visual attention span, supporting that it can provide a measure of the size of the orthographic grain used in reading***. To this end, we will summarise evidence linking the visual attention span to the acquisition of reading skills and orthographic knowledge and highlighting that its relation to reading arises from the component of visual and pre-orthographic processing that it reflects. The goal is to demonstrate that the visual attention span could be used to study the effects and interactions of factors influencing the use of lexical reading and larger orthographic grains, a core theme of the present study.

1.2 The role of the visual attention span in sight word reading and processing large orthographic grains

The ***visual attention (VA) span*** is the neuropsychological counterpart of the window of simultaneous visual attention (MTM model, Ans et al., 1998) when set to its maximum capacity (also see Bundesen, Habekost, & Kyllingsbaek, 2005; LaBerge & Samuels, 1974). The VA span is defined as the number of distinct visual elements that can be processed simultaneously in a multi-element array in a single fixation (Bosse et al., 2007). Thus, in the context of reading the VA span is related to the number and/or the size of the orthographic units that can be processed at a glance (Bosse & Valdois, 2009; Frey & Bosse, 2018). A number of different paradigms (some of which are presented in chapter 2), have been used to measure VA span skills. All of the most typically used paradigms include trials in which the participant is firstly cued to attend to the center of the screen (with the presentation of a centered fixation cross), and is then briefly presented (for 200 ms) with a centered multi-letter horizontal array, composed of consonants. The brief presentation of the multi-letter array ensures that the participant does not have time to perform a saccade or a second fixation. The consonants in the multi-letter array are: a) sufficiently spaced to reduce crowding effects, b) not repeated and, c) not word skeletons or multi-letter graphemes that could be processed as larger units. Depending on the paradigm the participant has to either report one cued letter or all of the letters of the array, or has to identify whether a specific letter was part of the multi-letter array (the target letter is presented after the presentation of the array). Traditionally, in tasks in which all the letters of the array must be reported order is not taken into account, meaning that performance is related to the correct processing of letter identity but not letter position. In tasks in which the array is followed by a cue, letter position is also taken into account, although the spaced presentation of the letters of the array decreases crowding and thus the difficulty of letter position coding. Overall, performance on these tasks allows the calculation of the number of elements that can be independently (i.e., not as multi-letter units or chunks) processed at a glance.

The present study focuses specifically on the ***VA span*** due to its particular role in in ***the acquisition of lexical orthographic representations***, in ***sight word reading***, and in the ***ability to efficiently process larger sub-lexical orthographic grains***. Nevertheless it should be noted that the VA span is not the only aspect of visual processing related to reading acquisition[4]. Initially, the VA span was studied in the context of dyslexia, and the theory that a VA span deficit could be a cause of dyslexia was put forward (Bosse et al., 2007). Subsequently, studies demonstrated that while most individuals with dyslexia show a phonological deficit, some show a VA span deficit in the absence of a phonological deficit, while others show both or neither deficit (Bosse et al., 2007; Dubois et al., 2010; Germano, Reilhac, Capellini, & Valdois, 2014; Lallier, Valdois, Lassus-Sangosse, Prado, & Kandel, 2014; Valdois et al., 2003; Zoubrinetzky, Bielle, & Valdois, 2014). Studies proceeded to demonstrate the contribution of VA span skills even to typical reading development, always accounting firstly for the contribution of phonological skills. These studies succeeded in linking the VA span to reading aloud (Bosse & Valdois, 2009; Lobier, Dubois, & Valdois, 2013), to eye movements in reading (Bosse, Kandel, Prado, & Valdois, 2014; Prado, Dubois, & Valdois, 2007; van den Boer, van Bergen, & de Jong, 2014, 2015), to spelling (van den Boer et al., 2015) and copying skills (Bosse et al., 2014). Finally, the effects of VA span skills on adult reading were also studied, albeit to a lesser extent, providing evidence that adult readers with dyslexia also show a VA span deficit (Lobier, Peyrin, Pichat, Le Bas, & Valdois, 2014), and that VA span skills can be related to skilled adult reading in certain cases (to be discussed in the next section: Awadh et al., 2016; Zhao, Kwok, Liu, Liu, & Huang, 2017). Table 1.1 includes a brief overview of all the studies which to our knowledge, have focused on the VA span and some studies that have been related to the debate on whether VA span skills contribute to reading skills independently of phonological skills. The results of

[4]Studies have focused on the role of different aspects of visual attention on reading development (Pammer, Lavis, Hansen, & Cornelissen, 2004; Vidyasagar & Pammer, 2010). Some of the aspects of visual attention that have been studied are: spatial attention (Facoetti et al., 2010, 2006; Franceschini, Bertoni, Gianesini, Gori, & Facoetti, 2017; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012), motion perception (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Gori, Seitz, Ronconi, Franceschini, & Facoetti, 2015) and visual search (Franceschini et al., 2012; Jones, Branigan, & Kelly, 2008). These studies have linked visual processing to both typical (Aghababian & Nazir, 2000; Franceschini et al., 2012; Plaza & Cohen, 2007) and atypical reading development (Demb, Boynton, & Heeger, 1998; Facoetti et al., 2010; Ferretti, Mazzotti, & Brizzolara, 2008; Sperling, Lu, Manis, & Seidenberg, 2006; Stein, 2001; Vidyasagar, 2013).

these studies, the most relevant of which are highlighted in the following paragraphs, support the use of the VA span as a valid visual measure of the bias towards lexical reading and larger orthographic grains.

Table 1.1: Table of studies on the VA span

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Studies using the most typical versions of VA span tasks					
Valdois et al., 2003	French	Two-case study (teenagers with dyslexia)	Global/Partial report	words (regular/irregular), pseudowords[a]	• The individual with specific difficulties in irregular word reading had a VA span deficit. • The individual with specific difficulties in pseudoword reading had a phonological deficit.
Bosse et al., 2007	French, English	children with and without dyslexia	Global/Partial report	words (regular/irregular), pseudowords	• A subgroup of children with dyslexia had a specific deficit in VA span skills. • VA span skills accounted for specific variance in reading, additionally to phonological skills. • Particularly reading speed and irregular word reading performance were predicted by the VA span.
Prado et al., 2007	French	children with and without dyslexia (those with dyslexia had a selective VA span deficit)	Global/Partial report	• words (regular/irregular), pseudowords • text reading and visual search	• Children with dyslexia processed a similar amount of letters in both text reading and visual search, and fewer letters than children without dyslexia in text reading. • The VA span was linked to the number of letters processed simultaneously (per fixation) in reading.
Lassus-Sangosse et al., 2008	French	children with and without dyslexia (those with dyslexia were separated into two groups, only one of which had phonological problems)	Global and Sequential report	words (regular/irregular), pseudowords	• Difficulties in the global (simultaneous) but not the sequential visual processing task were greater in the children with dyslexia without phonological problems. • Performance on both the simultaneous and sequential processing visual tasks contributed to reading, but performance on the simultaneous processing task independently contributed to both reading speed and accuracy.
Bosse & Valdois, 2009	French	children without dyslexia	Global/Partial report	words (regular/irregular), pseudowords	• Better VA span skills were linked to faster reading overall and more accurate irregular word reading.
Dubois et al., 2010	French	two-case study, children with dyslexia	Global/Partial report	words (regular/irregular), pseudowords	• Both children had a VA span deficit.
Peyrin et al., 2011	French	children with and without dyslexia (those with dyslexia had a VA span deficit)	Global report	• words (regular/irregular), pseudowords • visual categorization task (fMRI) with the manipulation of the type of character (letters vs. geometrical figures) and the visual attentional load (flanked vs. isolated condition).	• The contrast between activation on the flanked vs. the isolated condition (showing differences in attentional load and multi-element processing) elicited activation of the left SPL[b] in the controls, but not in the dyslexic children.
Lobier, Peyrin, et al., 2012	French	adults without dyslexia		visual categorization task	• This study identified the neural correlates related to visual multi-element processing, including the SPL bilaterally.

Continued on the next page

Table 1.1: Table of studies on the VA span (cont.)

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Lobier, Zoubrinetzky, & Valdois, 2012	French	children with and without dyslexia (those with dyslexia had a VA span deficit)	Global report	• words (regular/irregular), pseudowords • visual categorization task with the manipulation of the type of character (verbal vs. non-verbal).	• Children with dyslexia and a VA span deficit were also impaired on the categorization task independently of stimuli type. • VA span skills of the children without dyslexia were also linked to performance on the categorization task for non-verbal stimuli.
Peyrin et al., 2012	French	Two adults with dyslexia (one with a selective VA span and the other with a selective phonological deficit), and a group of adults without dyslexia	Global/Partial report	• words (regular/irregular), pseudowords • visual categorization task (fMRI) including the manipulation of the type of character (letters vs. geometrical figures).	• A neural and behavioural dissociation was reported between the VA span and phonological deficit. • For the individual with a VA span deficit, decreased activation of the SPL bilaterally (and the left supramarginal gyrus) was reported for the visual categorization task.
Lallier, Donnadieu, & Valdois, 2013a	French	children with and without dyslexia	Global report	• words (regular/irregular), pseudowords • dichotic listening task (simultaneous ,auditory mutli-element processing).	• Children with difficulties in the dichotic listening task also had a reduced VA span, and only a subgroup of these children had phonological difficulties.
Lallier, Donnadieu, & Valdois, 2013b	French	children with and without dyslexia	Global/Partial report	• words (regular/irregular), pseudowords • visual and auditory search tasks with the manipulation of the number of distractors.	• Visual search was worse in the group with dyslexia. • Both visual and auditory search performance were linked to the VA span but not the phonological skills of the group with dyslexia.
Lobier et al., 2013	French	children without dyslexia	Global report	• text reading • TVA (Theory of Visual Attention)-task requiring whole report with the manipulation of number of letters, position, masking and exposure duration.	• Both visual processing speed and visual short term memory as calculated based on the TVA-task predicted VA span. • VA span mediated the link between visual processing speed and reading speed.
Reilhac et al., 2013	French	adults with and without dyslexia (those with dyslexia had a VA span deficit)	Global report	Letter identity substitution task (judging whether two sequentially presented arrays are identical, fMRI)	• Two regions,the left SPL and the left vOT -related to substituted letter detection- were less activated in the group with dyslexia.
van den Boer et al., 2013	Dutch	children without dyslexia	Global report (but requiring correct order)	word, non-word reading (with the manipulation of length)	• Reading speed decomposed into an effect of overall reading speed and a length effect. • Individual differences in the length effect related both to VA span and phonological skills but not to rapid automatized naming.
Bosse et al., 2014	French	children without dyslexia	Global/Partial report	• eye movements during text reading • gaze lifts during text copying	• Better VA span skills were linked to copying more letters per gaze lift and to processing more letters per fixation in reading.
Germano et al., 2014	Brazilian Portuguese	children with and without dyslexia	Global report	word, pseudoword and text reading	• Children with dyslexia could be categorized into four groups: one with a phonological deficit, one with a VA span deficit, one with both and one with neither. • VA span skills contributed to reading after phonological skills were accounted for.

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Table 1.1: Table of studies on the VA span (cont.)

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Lallier et al., 2014	French-Spanish bilinguals	children with and without dyslexia (those with dyslexia had a VA span deficit)	Global/Partial report	• text, word (regular, irregular), pseudoword • orthographic knowledge test (tested with irregular words in French and orthographic choice in Spanish)	• Children with dyslexia performed worse on the VA span. • VA span skills related to both reading accuracy and speed in both Spanish and French (although there was more variance in accuracy for reading in French). • VA span skills were associated with orthographic knowledge in both languages.
Valdois, Peyrin, et al., 2014	French-Spanish	Case study of a bilingual with dyslexia and a VA span deficit (group of control children without dyslexia)	Global/Partial report	• words (regular/irregular), pseudowords • visual categorization task (fMRI) with the manipulation of the type of character (verbal vs. non-verbal).	• A VA span intervention improved both regular and irregular word reading in French. • It only modestly improved word reading speed in Spanish and did not improve pseudoword reading. • Thus the VA span intervention improved global processing and increased SPL activation bilaterally.
van den Boer et al., 2014	Dutch	children without dyslexia	Global report (but requiring correct order)	oral and silent word/pseudoword,sentence, and text reading	• VA span skills correlated with both oral and silent reading but had a unique significant contribution only for silent reading (after accounting for phonological skills and rapid automatized naming).
Zoubrinetzky et al., 2014	French	children with and without dyslexia	Global/Partial report	words (regular/irregular), pseudowords	• The group of children with dyslexia could be separated into four subgroups: four groups in dyslexics: one with a phonological deficit, one with a VA span deficit, one with both and one with neither.
van den Boer et al., 2015	Dutch	children without dyslexia	Global report (but requiring correct order)	word reading, spelling and orthographic choice task	• VA span skills were associated with reading fluency, orthographic knowledge and spelling skills.
Awadh et al., 2016	Arabic, French, Spanish	adults without dyslexia	Global/Partial report	text reading	• VA span skills were similar between the French and Spanish groups but reduced in the Arabic group (who also showed differences in left-right asymmetry related to reading direction). • VA span skills correlated with text reading only in the French group.
Lallier et al., 2016	French-Basque, Spanish-Basque	children without dyslexia	visual 1-back	words (regular/irregular), pseudowords, and text reading	• The French-Basque group had a better distribution of VA span skills. • The Spanish-Basque group performed better on the most difficult conditions of the phonemic awareness and pseudoword reading tasks.
Yeari et al., 2016	Hebrew	adults with and without dyslexia	Global report	Different versions of non-verbal character recognition task (presentation of a multi-element array and then forced choice between two alternative arrays manipulating discriminability)	• Adults with dyslexia performed poorly on the Global report task but did not perform worse than the group without dyslexia on the character recognition task.
Zhao et al., 2017	Chinese	adults without dyslexia	visual 1-back	oral and silent reading of characters and sentences	• VA span skills correlated to both oral and silent reading, more to the latter.

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Table 1.1: Table of studies on the VA span (cont.)

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Antzaka et al., 2018	French-Basque, Spanish-Basque	children without dyslexia	visual 1-back	text reading	• The French-Basque group were more biased towards processing larger multi-letter chunks and distributed attention homogeneously in the VA span task (in the more advanced group of readers).
Lallier et al., 2018	Arabic	children without dyslexia	visual 1-back	vowelized and non-vowelized text reading	• Only within the group of children who were better at reading the non-vowelized script (possibly related to stronger reliance on top-down contextual information and lexical reading), VA span skills correlated with reading
van den Boer et al., 2018	Dutch	adults with and without dyslexia,and malingerers	Global report (but requiring correct order)	• Global report with digits (but requiring correct order) • text, word and pseudoword reading	• On the global report with letters the group of adults without dyslexia outperformed the other two groups. • On the global report with digits the group of malingerers was the only one that performed worse than the other two groups.
Zhao et al., 2018a	Chinese	children with and without dyslexia	visual 1-back	reading of characters and sentences	• The group with dyslexia showed a VA span deficit in more advanced readers. • VA span skills correlated with morphological awareness.
Zhao et al., 2018b	Chinese	children without dyslexia and children with reading fluency difficulty	visual 1-back	reading of characters and sentences	• The group with reading fluency difficulties showed a VA span deficit. • VA span skills were associated with reading fluency at the sentence level for the readers without reading difficulties and at the character level for less fluent readers.
van den Boer & de Jong, 2018	Dutch	children without dyslexia	Global report (but requiring correct order)	• text, word and pseudoword reading	• VA span skills explained additional variance after accounting for rapid automatized naming and phonological awareness. • Individual differences in VA span skills were highly stable over time (assessed in Grade 3 then 4). • Controlling for autoregressive effects the effect of VA span skills on reading a year later were not significant (and vice versa).
Theoretical papers related to the VA span					
Valdois et al., 2004					• Overview of studies demonstrating the independence of phonological and visual attentional deficits in developmental dyslexia and studies showing the independent contribution of phonological and visual attentional skills to reading. • Proposition of a theoretical model of reading supporting of a causal link between a visual attentional disorder and a failure in reading acquisition.
Lallier & Valdois, 2012					• Contrasting simultaneous with sequential processing deficits.

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Table 1.1: Table of studies on the VA span (cont.)

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Frey & Bosse, 2018					• A theoretical review describing and contrasting the VA span, visual span and perceptual span.
Lallier & Carreiras, 2018					• A paper extending the "psycholinguistic grain size theory" (Ziegler & Goswami, 2005) to bilingualism with a focus on effects on visual and phonological grain size, the former related to VA span skills.
Studies referring to VA span skills but using other tasks					
Pammer et al., 2004	English	children with and without dyslexia		• symbol string sensitivity task (presentation of array followed by forced choice between two alternatives) • reading accuracy based on battery	• Children with dyslexia performed worse on the string sensitivity task. • Performance on the symbol-string task predicted a unique proportion of reading variability.
Hawelka & Wimmer, 2005	German	children with and without dyslexia		• version of partial report task using digits (multi-element processing task) • word and pseudoword list reading (eye movements recorded)	• Performance on the multi-element processing task was related to eye movements in reading. • Half of the children with dyslexia exhibited a multi-element processing deficit.
Kandel & Valdois, 2006	French, Spanish, and French-Spanish	children without dyslexia		word copying	• Spanish words copied without gaze-lifts as a whole, while in French words were copied using the syllable and letter as sub-lexical units.
Hawelka & Wimmer, 2008	German	adults with and without dyslexia		letter and pseudoletter target identification in a multi-element string (in this case the target was presented prior to the array)	• There was no difference in performance on the target identification between the group with and without dyslexia.
Jones et al., 2008	English	adults with and without dyslexia		• symbol string sensitivity task (similarly to Pammer et al., 2004) • visual search task • word and nonword reading	• The group of participants with dyslexia performed worse on the symbol string sensitivity and the visual search tasks. • Performance on these tasks correlated with non-word reading.
Ziegler, Pech-Georgel, et al., 2010	French	children with and without dyslexia		• task with horizontally presented array of symbols, digits or letters followed by a cue and two choices • regular, irregular and nonword reading	• Children with dyslexia showed deficits for letters and digits but not symbols.
Bosse et al., 2013	French	children without dyslexia		orthographic learning task using pseudowords and manipulating the amount of orthographic information presented simultaneously	• Orthographic learning was boosted when the novel orthographic string could be processed as a whole (all letters were presented simultaneously).

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Table 1.1: Table of studies on the VA span (cont.)

Paper	Language	Participants	VA span task	Reading/other tasks	Main results
Collis et al., 2013	English	adults with and without dyslexia (although those with dyslexia were in many cases self-diagnosed)		• task similar to Ziegler, Pech-Georgel, et al. (2010), but presenting nine rather than two alternatives • word and non word reading	• The group with dyslexia showed a deficit on the task using letters and digits, but not symbols. • The deficit was limited to position errors for crowded items in the symbol string processing task and correlated with letter transposition reading errors.
Holmes & Dawson, 2014	English	adults without dyslexia		• variant of global and partial report tasks (similar procedure, inter-letter spacing may differ) • lexical decision task	• Performance on the partial report task was related to the detection of letter misorderings in words and to decisions on regular words and pseudowords, but not difficult (strange) words. • When short-term phonological memory was accounted for, performance on global and partial report tasks did not predict lexical decision for either words or nonwords.
Lobier et al., 2014	French	adults with and without dyslexia (those with dyslexia had a VA span deficit)		visual categorization (how many characters of a category within the array) task with the manipulation of verbal and non-verbal categories	• Multi-element processing was linked to activation in parietal areas in the group without dyslexia. • Reduced SPL and vOT activation in the group with dyslexia regardless of stimuli type.
Onochie-Quintanilla et al., 2017	Spanish	children without dyslexia		• symbol string sensitivity task (similarly to Jones et al., 2008; Pammer et al., 2004) • word list reading	• Symbol string sensitivity correlated to reading speed in the difficult reading conditions (i.e., low frequency long words).
Banfi et al., 2018	German	children with and without dyslexia and a group with an isolated spelling deficit		• consonant and symbol visual 1-back • multi-letter strings based on six items • target appeared in the position at which it was present in the array	• No deficit reported for the children with dyslexia or the isolated spelling deficit

Note. [a] In the table, when referring to reading, if not specified the measure was reading aloud/oral reading, [b]SPL: Superior Parietal Lobule.

One of the reasons why the VA span is a good candidate as a measure of lexical processing and orthographic grain size is its implication in the acquisition of orthographic knowledge and lexical reading. Evidence of the role of VA span skills in the ***acquisition of lexical orthographic representations*** has been provided by a number of studies using different approaches. First of all, one study suggested that VA span skills, essential to global processing, would support the creation of lexical orthographic representations by demonstrating the importance of processing a novel orthographic string as a whole in orthographic learning (Bosse et al., 2013, regarding the importance of whole word orthographic processing also see: Adelman, Marquis, & Sabatos-DeVito, 2010; Grainger et al., 2016; Häikiö, Hyönä, & Bertram, 2015). Similarly, other studies have linked VA span skills to performance on tasks measuring orthographic knowledge (Lallier et al., 2014; van den Boer et al., 2015). On the other hand, the role of VA span skills in efficient ***sight word reading*** (i.e., accessing lexical orthographic representations) is showcased both by studies relating VA span skills to reading accuracy on irregular words, which must be processed as a whole for correct pronunciation (e.g. “yacht” in English, and “monsieur” in French, Bosse et al., 2007; Bosse & Valdois, 2009), and by a study demonstrating that a VA span intervention particularly boosted sight word reading (Valdois, Peyrin, et al., 2014). Furthermore, better VA span skills were linked to reading speed for both words and pseudowords, suggesting a larger span allows in the case of the former, efficient access to word orthographic representations (i.e., sight word reading), and in the case of the latter, ***efficient processing of larger orthographic grains*** (beyond the single letter/grapheme, Bosse et al., 2007; Bosse & Valdois, 2009; Germano et al., 2014). In a similar vein, better VA span skills have also been associated with: a) weaker length effects, indicating the processing of larger sub-lexical orthographic grains and/or boosted lexical processing (van den Boer et al., 2013), and b) higher-per fixation-information processing in text reading (Bosse et al., 2014; Prado et al., 2007), indicating it could reflect both higher visual processing speed (Lobier et al., 2013) and efficient use of top-down information (such as lexical processing). The hypothesis that a larger VA span could be related either better visual or lexical processing highlights that VA span skills might reflect both visual and orthographic processing, since the latter was suggested to be the interface between visual and linguistic processing (Grainger, 2017).

Despite the aforementioned evidence on the role of VA span skills in reading there is an ongoing debate regarding ***whether the role of the VA span in reading is independent of that of phonological skills*** (for two opposing views see: Lobier, Zoubrinetzky, & Valdois, 2012; Ziegler, Pech-Georgel, et al., 2010). The use of the VA span as a measure of visual orthographic grain size necessarily presupposes that its association with reading skills does not arise from sharing a common phonological component. Given the central role of grapheme-to-phoneme mapping in theories of reading development and models of skilled reading it comes as no surprise that phonological skills are considered a cornerstone of reading development (Berninger, Abbott, Nagy, & Carlisle, 2010; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1987), and have been linked to typical reading development (Brunswick, Neil Martin, & Rippon, 2012; Byrne & Fielding-Barnsley, 1989; Caravolas, Volín, & Hulme, 2005; de Jong & van der Leij, 1999; Ecalle & Magnan, 2007; Lafrance & Gottardo, 2005; Landerl & Wimmer, 2008; Lervåg, Bråten, & Hulme, 2009; Muter & Diethelm, 2001; Muter, Hulme, Snowling, & Stevenson, 2004; Öney & Durgunoğlu, 1997; Onochie-Quintanilla, 2016), while a phonological deficit has been suggested to be play a causal role in dyslexia (Rack, Snowling, & Olson, 1992; Ramus et al., 2003; Vellutino et al., 2004, but see: Blomert & Willems, 2010; Castles & Coltheart, 2004; Ramus & Szenkovits, 2008). Phonological skills are related to the capacity to identify, store and manipulate linguistic units of sound such as rimes, syllables and phonemes, and can be separated into three components: phonological awareness, phonological short term memory and naming speed (Wagner & Torgesen, 1987)[5]. The main argument against the VA span reflecting only visuo-attentional processes (Ziegler, Pech-Georgel, et al., 2010) lies in the use of linguistic stimuli (mostly letters) in the evaluation of VA span skills, thus recruiting processes that depend on phonological skills. As an example, since all tasks involve processing letters, it has been suggested that the linguistic symbol to sound mapping skills, rather than visuo-attentional skills, could explain the VA span - reading link (Ziegler, Pech-Georgel, et al., 2010). ***The following paragraph will provide evidence supporting that the role of the VA span in reading is in fact attributable to its visual and not its verbal component***, thus supporting that it could be the ideal candidate to quantify the influence of specific factors on the visual grain size in reading (that is in turn influenced by the orthographic grain size).

First of all in relation to dyslexia, studies have demonstrated that the VA span influences reading ability independently of phonological skills with the ***dissociation between a phonological and a VA span deficit*** in groups of children with dyslexia (Germano et al., 2014; Valdois et al., 2003; Zoubrinetzky et al., 2014). This dissociation is further supported at the neural level (Peyrin et al., 2012), with

[5]This section presents the influence of a particular component of visual processing on reading, and has also briefly underlined the influence of phonological skills. Other cognitive contributors of reading skill (e.g, rapid automatized naming: Kirby et al., 2010; Norton & Wolf, 2012, vocabulary knowledge: Nation & Snowling, 2004; Verhoeven & Perfetti, 2011, and morphological awareness: P. N. Bowers, Kirby, & Deacon, 2010; Carlisle & Feldman, 1995; Nagy, Berninger, & Abbott, 2006) that are not directly related to the present work have not been presented although they are clearly important in developing literacy.

a VA span deficit being related to decreased activation in the ***superior parietal lobule (SPL), considered an attentional region***, while the phonological deficit was related to decreased activation in the left inferior frontal gyrus, typically involved in phonological processing. The SPL has also been found to be less activated in adult readers with a VA span deficit as compared to controls (Lobier et al., 2014), and more activated when performing tasks involving multi-element processing (Lobier, Peyrin, et al., 2012; Reilhac et al., 2013), or as a result of a VA span intervention (Valdois, Peyrin, et al., 2014). On the other hand, studies have also aimed to demonstrate that the VA span-reading link is not dependent on its phonological component by ***testing VA span skills with non-linguistic stimuli*** (Lobier, Zoubrinetzky, & Valdois, 2012, but: Ziegler, Pech-Georgel, et al., 2010), by testing VA span skills while ***taxing phonology*** (Valdois, Lassus-Sangosse, & Lobier, 2012), or by ***employing tasks that focus on categorization*** rather than identification of the stimuli in the presented array (e.g., how many items of a target category were presented in a multi-element array including items of different categories: letters, letter-like characters and digits, Lobier, Peyrin, et al., 2012; Lobier et al., 2014). The aforementioned studies support that the role of the VA span in reading is related to its visual rather than its verbal component. We thus consider that it can reflect the modulations of orthographic grain size from the perspective of visual demands.

Key points

To sum up, this section introduced ***the VA span, a component of visual attention that in the context of reading reflects the number/size of orthographic units that can be processed at a glance***. It highlighted the particular importance of VA span skills in the ***acquisition of lexical orthographic representations***, in ***sight word reading*** and ***processing larger sub-lexical orthographic grains***. The next section will proceed to introduce the main factors whose influence we consider could modulate the size of the orthographic grain in reading. The core theme of this thesis will revolve around how these specific factors may modulate the orthographic grain size, and how this can be investigated through the lens of the VA span. More specifically, the next section will discuss how the manner in which the word's constituent ***orthographic grains map onto sound (phonology) and meaning (semantics)*** can also influence the use of ***sight word reading*** and ***reliance on larger orthographic grains***. It will also discuss how these factors may influence reading both ***within a language*** (and thus depending on the word to be read) and ***cross-linguistically***.

1.3 Factors influencing the mappings between orthographic grains onto phonology and semantics

1.3.1 Mapping of orthographic grains onto phonology: Irregular words and orthographic depth

One of the factors that has been clearly related to differences in the use of larger or smaller orthographic grains and to the reliance on sight word reading is the degree of consistency between grapheme-to-phoneme mappings. ***Within a language***, this is showcased by the presence of ***irregular or exception words***, which as mentioned previously, must be processed as a whole in order to achieve the correct pronunciation (e.g. "yacht"-/'jɒt/, "monsieur"-/məsjø/). Given that these words cannot be correctly decoded based on sub-lexical orthographic grains, they will bias the reader more towards sight word reading. On the other hand, even when words include regular mappings from orthography to phonology, some may include larger graphemes, also biasing the reader towards the processing larger orthographic grains (e.g., "though"-/'ðəʊ/ in English, and "lisaient"-/lizɛ/ in French). Difficulty reading irregular words has been particularly linked to surface dyslexia and to VA span skills (Bosse et al., 2007; Bosse & Valdois, 2009). Nevertheless, we particularly focus on the consistency and complexity of grapheme-to-phoneme mappings ***cross-linguistically*** and how cross-linguistic differences in these aspects of print to sound mapping may influence the bias towards sight word reading and orthographic grain size.

As described in the first section of the introduction, learning to map graphemes onto phonemes is the first step in learning to read in all languages with alphabetic orthographies. Indeed, alphabetic orthographies predominantly reflect a grapheme-to-phoneme mapping system, although some orthographies-like English-include a degree of morpheme to phoneme mapping (Frost, Katz, & Bentin, 1987). This decreases the consistency of grapheme-to-phoneme mappings, subsequently increasing the difficulty of learning to read. The consistency with which the graphemes of the written language are mapped to the phonemes of the spoken language when reading, and in the opposite direction when writing, is referred to as orthographic depth (Frost & Katz, 1989; Katz & Frost, 1992). The following paragraphs will describe ***how alphabetic languages may differ cross-linguistically regarding orthographic depth and how these differences can influence sight word reading, and reliance on larger orthographic grains and thus larger visual grains***.

In many cases, as in English, decreased consistency in grapheme-to-phoneme mappings (reading) is related to decreased consistency in phoneme to grapheme mappings (spelling), leading to similar difficulties in both learning to read and in learning to spell. Nevertheless in other languages, mappings can be more consistent in one direction than in the other. This is the case for French, in which grapheme-to-phoneme mappings are inconsistent, but to a lesser degree than phoneme to grapheme mappings (Schmalz, Marinus, Coltheart, & Castles, 2015). ***Focusing on grapheme-to-phoneme mapping (reading)***, the concept of orthographic depth encompasses two aspects: the complexity and the unpredictability (or inconsistency) of these mappings (Schmalz et al., 2015). Learning to read in shallow orthographies, like Spanish or Italian, involves learning mostly simple grapheme-to-phoneme mappings. In most cases, single-letter graphemes correspond to phonemes (e.g., in Spanish, the letter “t” is always pronounced as the phoneme /t/), and there are few cases in which accurate mapping depends on neighbouring letters (e.g., in Spanish, “c” followed by “h” is a digraph that is pronounced /tʃ/, “c” followed by “a”, “o”, “u” or other consonants is pronounced /'k/ and “c” followed by “e” or “i” is pronounced /θ/). In deeper orthographies, like French or English, learning to read involves grasping more complex grapheme-to-phoneme mappings. Examples of this complexity include the higher number of mappings between multi-letter graphemes and phonemes (e.g., in French “ou”-/u/, “eau”-/o/, “aie”-/ϵ/, “aient”-/ϵ/, “ph”-/f/), and the more common dependence of accurate mapping on factors such as: neighbouring letters, or letter position within the word (e.g., in French many letters are not pronounced at the end of a word).

Cross-linguistic studies have highlighted some of the ***effects of grapheme-to-phoneme mapping inconsistencies on reading development and orthographic grain size***. Firstly in deep orthographies, larger inconsistencies in grapheme-to-phoneme mappings delay the acquisition of accurate decoding skills (Caravolas, Lervåg, Defior, Seidlová Málková, & Hulme, 2013; N. C. Ellis & Hooper, 2001; Frith, Wimmer, & Landerl, 1998; Katz & Frost, 1992; Share, 2008; Ziegler & Goswami, 2005). On the other hand, in shallow orthographies like Spanish, German or Finnish, accurate decoding is acquired after the first year of formal reading instruction (Aro & Wimmer, 2003; Defior, Martos, & Cary, 2002; Seymour, Aro, & Erskine, 2003). A side-effect is that reading skill and difficulties are primarily evaluated through measures of speed in shallow orthographies (Landerl et al., 2013; Muller & Brady, 2001; Serrano & Defior, 2008; Seymour et al., 2003). Moreover, readers of shallow orthographies rely on grapheme-to-phoneme conversion in reading (Goswami, 1998; Goswami, Gombert, & de Barrera, 1998; Goswami, Porpodas, & Wheelwright, 1997; Holopainen, Ahonen, & Lyytinen, 2002; Rau, Moll, Snowling, & Landerl, 2015; Wimmer & Goswami, 1994), while ***readers of deeper orthographies rely on larger phonological grains*** (Ziegler & Goswami, 2005), thus demonstrating larger effects of rimes and orthographic and phonological familiarity (Goswami, 1998; Goswami et al., 1998, 1997; Treiman, Goswami, & Bruck, 1990). Reliance on larger grains is also supported by cross-linguistic differences in patterns of errors. More specifically, it has been shown that readers of English, as compared to readers of more shallow orthographies, are more likely to perform ***lexicalisation errors*** when reading, due to their ***reliance on lexical orthographic representations and sight word reading*** (N. C. Ellis et al., 2004). Moreover, it has also been shown that the effects of complexity and inconsistency can be similar and lead to a boost in lexical over sub-lexical processing efficiency both when when comparing reading more vs. less consistent words (English) and more vs. less complex words (French, Schmalz, Beyersmann, Cavalli, & Marinus, 2016). Possibly in both cases sub-lexical processing efficiency is reduced due to the competition between the mapping of different sizes of graphemes to phonemes producing incompatible phonological outputs. Notwithstanding, similar cognitive skills have been found to contribute to reading development in alphabetic orthographies differing in orthographic depth (Caravolas et al., 2012; Furnes & Samuelsson, 2011; Georgiou, Papadopoulos, Fella, & Parrila, 2012; Georgiou, Parrila, & Papadopoulos, 2008; Landerl et al., 2013; Moll et al., 2014; Patel, Snowling, & de Jong, 2004; Vaessen et al., 2010).

Overall according to the psycholinguistic grain size theory, the increased complexity of grapheme-to-phoneme mappings ***in deeper orthographies, leads readers to rely on processing more letters, or larger orthographic and phonological grains, in order to read accurately (Ziegler & Goswami, 2005)***. It should be noted that this strategy is fully successful only when these mappings are also reliable. In Spanish and Basque, grapheme-to-phoneme mappings are reliable and maintained within different lexical units. For the vast majority of words this is also the case in French (exceptions exist such as the previous example of the irregular word “monsieur”), but not in English, as showcased by the classical example of the pronunciation of “pint” (/’paɪnt/) as compared to “mint” (/’mɪnt/) and “hint” (/’hɪnt/). As a result of this unreliability, errors when reading in English may occur even after the correct grapheme-to-phoneme mappings have been acquired, since in many cases lexical information is necessary for correct pronunciation. In fact English is considered the least consistent of all alphabetic scripts (Ziegler, Stone, & Jacobs, 1997) and has been suggested to be an outlier orthography (Share, 2008).

The ***grain size accommodation hypothesis*** (Lallier & Carreiras, 2018) extends the psycholinguistic grain size theory to accommodate results in ***bilinguals learning to read in two different alphabetic orthographies*** (e.g., English and Welsh). In line with what has been proposed above, bilinguals learn to read more rapidly in the orthography with more consistent and simple grapheme-to-phoneme mappings (in this case Welsh), and ***rely on smaller grains in their shallow orthography*** (Lallier et al., 2014). Nevertheless, cross-linguistic transfer (that has been reported in reading-related skills of bilinguals: Durgunoğlu, 2002; Niolaki & Masterson, 2012; Ramírez, Chen, & Pasquarella, 2013; Saiegh-Haddad & Geva, 2008) leads ***grain size to be influenced by both the bilingual's languages***. As a result a bilingual individual learning to read in two shallow orthographies will be sensitive to smaller phonological and orthographic grains than an individual learning to read in a shallow and a deep orthography. This will lead to differences in both ***visual and orthographic grain size*** (Lallier & Carreiras, 2018) when reading in either language. Differences in orthographic depth have in fact been linked to differences in ***VA span skills***, which have been found to either play a ***more important role when reading in a deeper orthography*** (in line with their particular role in reading irregular words: Bosse et al., 2007), or alternatively ***readers of deeper orthographies*** have been found to have ***improved distribution of VA span skills*** (Lallier et al., 2016) or to be better at multi-letter processing (Lallier, Carreiras, Tainturier, Savill, & Thierry, 2013).

Key points

The previous paragraphs highlight that ***the higher inconsistency and complexity of grapheme-to-phoneme mappings*** leads readers to rely more on ***sight word reading*** and ***processing larger sub-lexical orthographic grains***, reflected by differences in the VA span. The following section will proceed to present how the manner in which the word's constituent ***orthographic grains map onto sound (phonology) and meaning (semantics)*** can also influence the use of ***sight word reading*** and ***reliance on larger orthographic grains*** both within a language and cross-linguistically, with a focus on ***morphological structure at the level of the word***.

1.3.2 Mapping of orthographic grains onto semantics: Morphemes as sub-lexical building blocks

The introduction thus far has presented the process of word reading assuming that words can either be read as a whole or based on smaller or larger sub-lexical orthographic grains. The size of these orthographic grains has been suggested to be influenced by the reader's skill and visual/orthographic processing abilities, by the size/consistency of the word's grapheme-to-phoneme mappings, and more generally by the overall orthographic depth characterizing the mappings from spoken to written language. At no point have semantics, and thus the aspect of meaning, been addressed at the sub-lexical level of word processing. Nevertheless, while in some cases the smallest meaningful unit is indeed the word (simple words), in other cases a word can be broken down into even smaller meaningful units (complex words). This is the reason for which morphemes, rather than words, are defined as the minimal units of language with meaning and grammatical function (Aronoff & Fudeman, 2005): lexical morphemes have semantic meaning, while grammatical morphemes specify relationships between lexical morphemes.

Some of the words we commonly use are morphologically simple, consisting of a single morpheme, but many are in fact morphologically complex, consisting of two or more morphemes. Morphemes are further characterized as being free or bound. Those that can constitute a morphologically simple word are free morphemes, while those that are only encountered within morphologically complex words are bound morphemes (or affixes) and are either inflectional or derivational[6] (Parker & Riley, 2005). Affixes can be attached to the stem, either as prefixes (before the stem), suffixes (after the stem), or more rarely as infixes (within the stem), or circumfixes (two-part affixes, between which the stem is placed, Aronoff & Fudeman, 2005). The influence of morphemes both in language processing (e.g., Ullman, 2001) and reading (e.g., Amenta & Crepaldi, 2012) constitutes a central and debated topic in cognitive research. However, the following paragraphs we will focus directly on ***how the mapping of sub-lexical orthographic grains onto morphemes*** in simple as compared to complex derived words may influence both: the bias towards ***sight word reading***, and the ***size of the orthographic grain*** when learning to read, focusing firstly on effects ***within a language***.

As described previously, readers increasingly rely on larger orthographic grains during reading acquisition (Ehri, 2005; Share & Stanovich, 1995). This is the case even when the grapheme-to-phoneme mappings are consistent, and thus the use of larger orthographic grains is not necessary for accurate reading. In support of this claim, studies in shallow orthographies have shown: a) that reading development gradually transitions from processing individual graphemes to processing lexical orthographic units (Cuetos & Suárez-Coalla, 2009) and sight word reading (Defior

[6]The distinction between derivational and inflectional affixes is not always clear. However, for our purposes it is easier to characterize derivational affixes as those changing the category of the free lexical morpheme to which they are appended (e.g., the “-er” in “hunter” is a derivational suffix, as opposed to the “-s” in “cats” that is an inflectional suffix). Moreover, it is considered that inflection is motivated by syntax (Aronoff & Fudeman, 2005) producing a word that can grammatically fit within a specific position of a sentence while morphology creates new lexical items.

et al., 2002; Orsolini, Fanari, Tosi, De Nigris, & Carrieri, 2006; Wimmer & Goswami, 1994; Zoccolotti, de Luca, Di Filippo, Judica, & Martelli, 2009), and b) that ***readers gradually rely on larger units*** at the sub-lexical level, ***such as morphemes*** (Burani, 2009, or on reading by analogy: Sebastián-Gallés, 1991).

More specifically regarding the influence of morphemes, studies on ***reading aloud*** have demonstrated that children are sensitive to the presence of both stems and derivational affixes when reading in alphabetic orthographies (Angelelli, Marinelli, & Burani, 2014; Burani, Marcolini, De Luca, & Zoccolotti, 2008; Burani, Marcolini, & Stella, 2002; Carlisle & Stone, 2005; Colé, Bouton, Leuwers, & Sprenger-Charolles, 2012; Deacon & Francis, 2017; Deacon, Whalen, & Kirby, 2011; Marcolini, Traficante, Zoccolotti, & Burani, 2011; Suárez-Coalla & Cuetos, 2013; Traficante, Marcolini, Luci, Zoccolotti, & Burani, 2011). More specifically in English, Carlisle and Stone (2005) found that morphologically complex derived words were read faster, while two other studies (Deacon & Francis, 2017; Deacon et al., 2011) focusing on the effects of whole word and stem frequency, demonstrated that stem frequency influenced naming speed, particularly when whole word frequency was low and thus the word was unlikely to be processed as a whole. One study found derived words were read faster than morphologically simple words by early and more advanced typically developing readers (Alessio, Jaichenco, & Wilson, 2018). Similarly, other studies have found an advantage when reading derived as compared to simple words only for low frequency words (Angelelli et al., 2014; Marcolini et al., 2011), or for poor readers (Burani et al., 2008; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013), or when reading morphologically complex as compared to simple pseudowords (Angelelli et al., 2014; Burani et al., 2008, 2002). This suggests that the ***"morphological benefit"***-the advantage in reading complex as compared to simple words-is found when the word cannot be processed as a whole through sight word reading. Moreover, it suggests that ***the presence of morphemes in a word that is unfamiliar***, and thus must be processed sub-lexically, ***allows the reader to process larger orthographic grains more efficiently*** (and their respective phonological grains).

An additional question that arises is ***whether both the stem and the derivational affix*** help the reader process ***larger orthographic grains***. Many of the aforementioned studies included morphologically complex pseudowords consisting of both a real stem and a real suffix in a non-existing combination (+stem+suffix, e.g., Angelelli et al., 2014; Burani et al., 2008), thus not disentangling the effects of the stem as opposed to the suffix. Moreover, given that studies have demonstrated both effects of stem frequency (Deacon & Francis, 2017; Deacon et al., 2011) and suffix frequency (in lexical decision: Lázaro, Acha, de la Rosa, García, & Sainz, 2017), both morphemes could provide a boost in naming. The question has been further investigated through studies on naming that manipulate the structure of morphologically complex pseudowords (Colé et al., 2012; Traficante et al., 2011). These studies included pseudoword stimuli consisting of two real morphemes (+stem+suffix) in a non-existing combination, one real morpheme and a pseudomorpheme (+stem-suffix in: Colé et al., 2012, and both +stem-suffix and -stem+suffix in: Traficante et al., 2011), or no real morphological constituent (-stem-suffix). In the study by Colé et al. (2012) the results showed that pseudowords composed of two real morphemes conferred a larger advantage than those only including a real stem (although both types of item were read faster and more accurately than pseudowords with no real morphological constituent). Traficante et al. (2011) showed a benefit in naming accuracy for pseudowords including either stems and/or suffixes, but a benefit for speed only when a real stem was part of the pseudoword, showing that in naming, speed may be more influenced by the presence of the stem. These results suggest that ***both types of morpheme could boost orthographic grain size when processing unfamiliar words***, with the stem possibly being more influential in reading speed.

The influence of morphemes on identifying a word has also been studied through ***lexical decision*** paradigms including both complex and simple words and pseudowords (Burani et al., 2002; Duncan, Gray, Quémart, & Casalis, 2010; Jaichenco & Wilson, 2013; Lázaro et al., 2017; Lázaro, Camacho, & Burani, 2013). Overall, the findings converge in that the presence of morphemes boosts the identification of complex words and inhibits performance in the case of complex pseudowords (Burani et al., 2002; Duncan et al., 2010; Jaichenco & Wilson, 2013), suggesting that the presence of sublexical orthographic grains that map onto morphemes lead to a boost in the activation of lexical orthographic representations (that favours the identification of complex words and disfavours the identification of pseudowords). Moreover, the reported stem and suffix frequency effects once again support ***the influence of both constituent morphemes in word identification*** (Lázaro et al., 2017, 2013). Lexical decision studies have also investigated the role of complex pseudoword structure on processing (Casalis, Quémart, & Duncan, 2015; Hasenäcker, Schröter, & Schroeder, 2017; Quémart, Casalis, & Duncan, 2012). These studies reported less accurate identification of pseudowords including both stems and suffixes (Casalis et al., 2015; Quémart et al., 2012) while slower responses were observed either when pseudowords included stems and/or suffixes (Quémart et al., 2012), or when pseudowords included suffixes (Casalis et al., 2015).

The above studies overall indicate that ***the mapping of sub-lexical orthographic (and thus phonological) grains onto morphemes*** influences the performance of readers who are learning to read ***within a language***. More specifically, the presence of morphemes may boost the activation of lexical orthographic representations and ***sight word reading*** and allow readers to ***process larger orthographic grains*** sub-lexically. Notably, it has been suggested that for highly skilled readers who by default rely on sight word reading, drawing attention to the morphological constituents of a word may in fact have a “detrimental” effect on reading aloud by causing interference in lexical processing (Angelelli et al., 2014, and in eye-tracking: Häikiö, Bertram, & Hyönä, 2011). Recently, it has also been suggested that the presence of sub-lexical morphemes in words could also modulate the visual attentional demands of their processing (Burani, Marcolini, Traficante, & Zoccolotti, 2018).

To our knowledge, there are no studies focusing on whether ***cross-linguistic*** differences in the mapping of orthography onto meaning, or more specifically the morphological structure of the word, influences visual/orthographic processing when reading ***in alphabetic orthographies***. Nevertheless, while languages with alphabetic orthographies share many similarities at the level of the writing system, their differences at the level of spoken language may translate into differences when processing written language. Such differences are a language’s morphosyntactic or phonological characteristics. Individual sensitivity to these characteristics may differ depending on their salience in the language and subsequently influence processing in reading. One example is that morphological awareness develops earlier in some languages (Duncan, Casalis, & Colé, 2009) and that this may also lead to children’s greater ability to attend to morphemes when reading (Casalis et al., 2015; Diamanti, Goulandris, Campbell, & Protopapas, 2018; Gillis & Ravid, 2000). Some of these cross-linguistic differences may in fact interact with the factor of orthographic depth. For example, in deeper orthographies such as French or English, morphemes can facilitate disambiguation between possible pronunciations of an orthographic unit (Frost et al., 1987; Peereman, Sprenger-Charolles, & Messaoud-Galusi, 2013; Rastle, 2018), thus further increasing the relevance of sensitivity to the mappings between orthographic grains and morphemes.

Key points

This section introduced the question of how and when the mapping of ***sub-lexical orthographic grains onto morphemes*** can influence ***sight word reading*** and the use of ***larger orthographic grains in reading development***, and whether the importance of these mappings and their influence in reading could differ cross-linguistically. In the following and final section of the introduction we will ***summarize the main points*** that were made in the introduction and ***frame the central open questions*** that this thesis attempts to address.

1.4 The present study

The previous sections outlined how reading skill, word familiarity, visual/orthographic processing and differences in the consistency of grapheme-to-phoneme and grapheme-to-morpheme mapping may modulate the degree to which individuals rely on sight word reading or on larger sub-lexical orthographic grains when reading in alphabetic orthographies (for a summary see figure 1.5). The present work will use the VA span as a measure of orthographic grain size with the aim to further investigate two topics that are relatively unexplored:

- The influence of cross-linguistic differences on the size of the visual and orthographic grain in reading, as assessed by VA span skills.
- How the word's morphological structure, modulates sight word reading and the size of the orthographic grain and thus VA span demands in reading and reading-related tasks.

These questions will be addressed through four different studies that constitute four different chapters of the present thesis. The first two cross-linguistic studies address the first topic and the last two studies that are in Basque address the second topic. Both the first and the third studies offer a developmental perspective on reading, including both early and more advanced readers in a cross-sectional design and thus also investigate how the development of reading skills could interact with the investigated factors influencing sight word reading and grain size. Apart from Basque, the other languages that are studied in the first and second cross-linguistic studies are Spanish and French. As aforementioned, all studies are centered around the VA span in reading, and how its role may be modulated reflecting differences in orthographic grain size, which is in turn influenced by the other factors we study: the language's orthographic depth and morphological richness, the word's morphological structure and familiarity, and the individual's reading skill. Therefore, before proceeding to the chapters presenting these four studies, the following chapter will provide both a description of the Basque language and its commonalities/differences and proximity with Spanish and French, as well as the tasks used to measure VA span skills in each of the following studies.

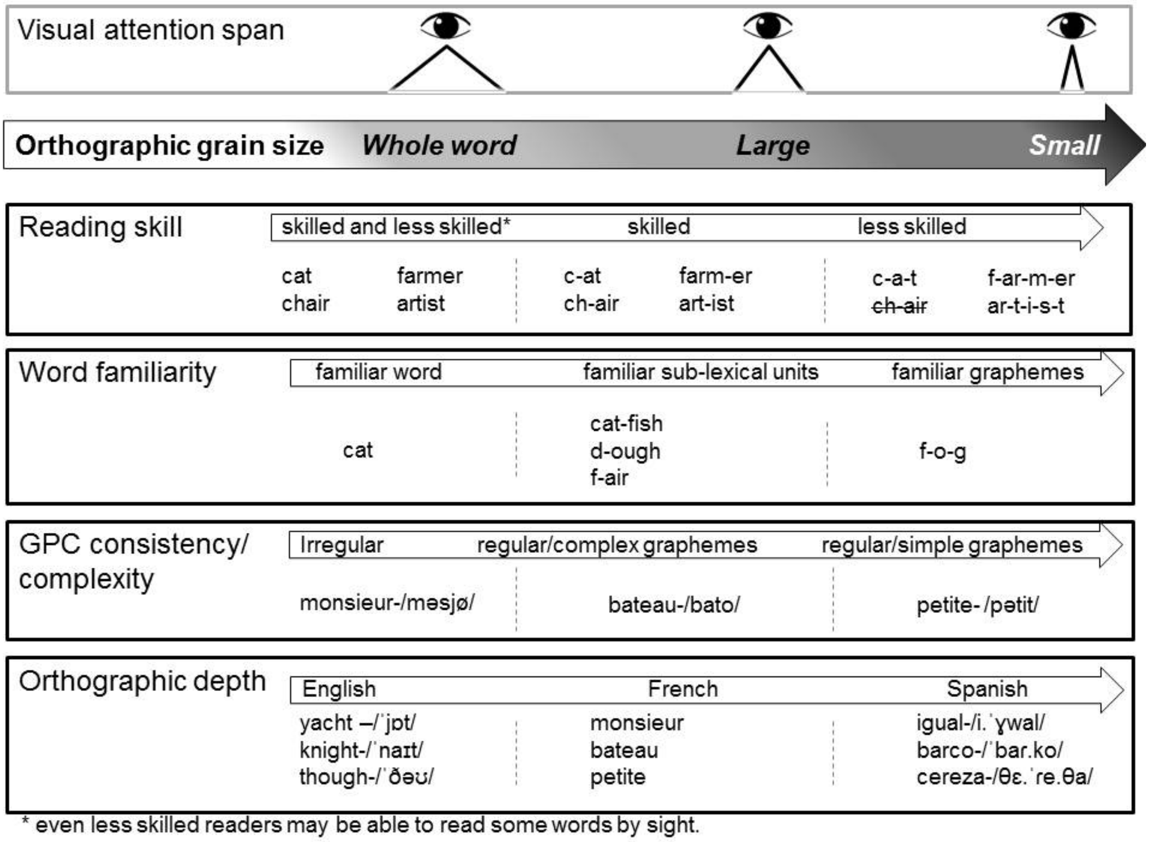


Figure 1.5: An overview of the presented factors modulating sight word reading and orthographic grain size and how the VA span might be associated to different visual orthographic grain sizes of reading.

The first study (page 47) presented in this thesis is based on a published article (Antzaka et al., 2018) co-authored with Clara Martin, Sendy Caffarra, Sophie Schlöffel, Manuel Carreiras and Marie Lallier. The second study (page 71) is not published, although some of the presented data has been published in Awadh et al. (2016). The third (page 87) and fourth studies (page 109) are (at the time the thesis was written) submitted for publication. These studies are coauthored with Joana Acha, Manuel Carreiras and Marie Lallier. All related publications are presented in the publications section (page 149). Some material from each of these papers has also been incorporated into this introductory chapter.

Finally, after the presentation of all four studies, the final chapter (the general discussion) will provide an overview of the most important points of our studies, comparing and contrasting them with the previous literature. Moreover, it will discuss the general implications of these results and suggest future directions in this field of research, highlighting the outstanding questions.

Chapter 2

Methodological Considerations

This chapter will provide a brief overview of two central issues of all four of our studies: some information on Basque, and a description of the VA span tasks. This information is included in a separate chapter in order to be more easily located within the thesis and to also avoid unnecessary repetition in the following chapters.

2.1 The Basque language

Basque is spoken in a region situated in the western Pyrenees, stretching from northern Spain to southern France and referred to as the Basque country. The region is heterogeneous both culturally and linguistically due to the influence of multiple factors such as: the interaction with the Spanish or French languages and culture, the status of the Basque language in different parts of the region, and the presence of different dialects of Basque. The Basque language is co-official in the Spanish but not the French region of the Basque country since 1980 (according to the Basque Language Academy). As a result, the presence of Basque in education, culture and society is more prominent in the Spanish region of the Basque country, which includes the Basque Autonomous Community. Therefore, in the Spanish part of the Basque country, Basque is spoken in public organisations, hospitals, universities, shops, films, theatres and in the media. This is also true in the French region but to a lesser degree.

A result of the coexistence of these languages is that there are two major Basque populations: the Spanish-Basque and the French-Basque populations. In each of these populations individuals may differ regarding the language they acquired first (L1), the age at which they acquired the other language (AoA, with some bilinguals simultaneously acquiring both languages from birth) and the degree of proficiency in the two languages, a factor that can also change across the lifespan.

An important factor to take into account given our focus on reading development is that of schooling in the Basque country. Although more widespread in the Spanish region, ikastolas across the Basque country are schools in which children are taught predominantly in Basque, with Spanish and French taught as a compulsory topic but all other subjects, including reading and writing, taught in Basque (referred to as "modelo D" in the Spanish-Basque region). Alternatively in the Spanish-Basque region, children may also attend schools in which half of the subjects are taught in Basque and the other half are taught in Spanish ("modelo B"), thus learning to read in both languages simultaneously.

The majority of the following studies will focus on reading in Basque. Nevertheless, both cross-linguistic studies involve Spanish and French readers so it would be useful to give a brief description of the similarities and differences between Basque and these languages that are more commonly encountered in psycholinguistic research and thus more familiar. Regarding language proximity it should be noted that Spanish and French are both Romance languages with many similarities both at the lexical and grammatical level, while Basque is an isolated language, descendant of Pre-Indo-European languages (for a review on Basque see: Laka, 1996). The proximity of the languages has led to the presence of many cognates, particularly in Basque and Spanish. At the level of grapheme-to-phoneme mappings there is a large overlap between Basque and Spanish, which are both consistent and simple orthographies and also share many phonemes. French on the other hand has a larger phonemic inventory and a more complex orthography, although the orthography is similarly consistent in its grapheme-phoneme mappings, with the exception of the presence of some irregular words. Thus Spanish-Basque bilinguals learn to read in two similarly simple and consistent orthographies that also have a large degree of overlap in their grapheme-to-phoneme mappings. On the other hand French-Basque bilinguals learn to read in one simple and consistent orthography and in a consistent but more complex orthography. The question of whether this would influence skills related to reading development is addressed in the first study.

Despite the overlap between Spanish and Basque at the level of grapheme-to-phoneme mappings, the proximity of Spanish and French is clear in most other aspects. Although all three languages are synthetic, combining morphemes in words and using both inflectional and derivational morphology, Basque, similarly to Finnish and Turkish is also agglutinative. Derivational morphemes affect meaning, whilst inflectional morphemes affect syntax, but both are highly productive in Basque. Additionally, they are stacked at the end of the stem, leading to the formation of long, morphologically complex words. Some examples that were included in Acha, Laka, Landa, and Salaburu (2014) are the following:

the word “etxe”-house, can be found in “etxe-a”-the house, “etxe-a-ren”-of the house, “etxe-gile”-house builder, “etxe-ra”-to the house, and “etxe-arentzat”-for the house. These characteristics of the Basque language have led to particular interest in morphological processing in this language (e.g., Duñabeitia, Laka, Perea, & Carreiras, 2009; Duñabeitia, Perea, & Carreiras, 2007), and evidence suggests that morpheme internalization is attained very early during reading development (Acha, Laka, & Perea, 2010). The issue of processing derived as compared to simple words and pseudowords in Basque is addressed in the third and fourth studies. As mentioned previously, studies on alphabetic orthographies have cross-linguistically compared reading development in alphabetic languages mainly focusing on differences in orthographic depth. Nevertheless, some studies have shown different sensitivity to sub-lexical morphemes depending on language morphology (Casalis et al., 2015), while others have demonstrated that similar reading predictors are involved in learning to read in alphabetic languages with shallow agglutinative as compared to fusional morphologies (e.g., comparing Finnish to other alphabetic orthographies: Aro & Wimmer, 2003; Seymour et al., 2003). We will address the issue of cross-linguistic differences depending on language morphology in the second study.

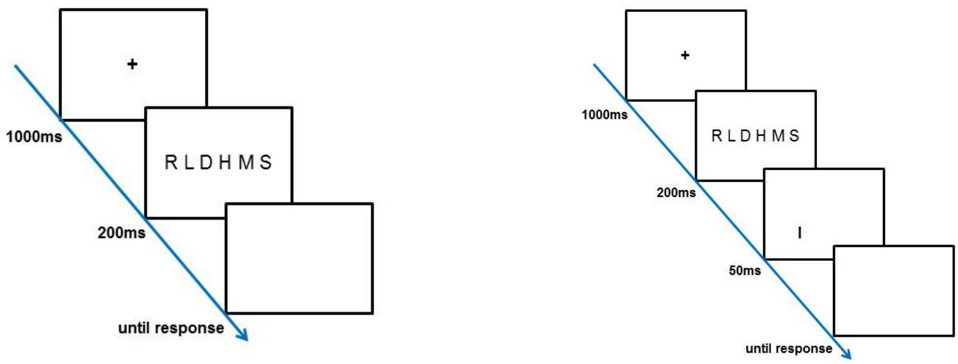
There are more aspects of Basque at the morphosyntactic and word order level that differ from Spanish and French and have drawn the interest of psycholinguistic research (Carreiras, Duñabeitia, Vergara, de la Cruz-Pavía, & Laka, 2010; Erdocia, Laka, Mestres-Missé, & Rodriguez-Fornells, 2009; Laka & Erdocia, 2005; Laka, Santesteban, Erdocia, & Zawiszewski, 2012; Zawiszewski, Gutiérrez, Fernández, & Laka, 2010). At the morphosyntactic level Spanish and French are nominative-accusative languages while Basque is an ergative-absolutive language. To provide an overly simplified description, this means that in Spanish and French the subject of both transitive and intransitive verbs appears in the nominative case and the object of transitive verbs appears in the accusative case. In Basque, the subject of a transitive verb will bear ergative case marking while the subject of an intransitive verb and the object of transitive verbs appears in absolutive case. Regarding word order, these languages differ in relation to the head-parameter. Briefly, Spanish and French are head-initial, meaning that the head of the phrase is placed before its complements while the opposite is true for Basque. At the sentence level, it has been suggested that Basque has relatively free word order (although often referred to as an SOV-subject-object-verb language) while Spanish and French are SVO languages. These characteristics are mentioned in order to showcase that agglutination is not the only feature of Basque that sets it apart from French and Spanish, even though the present work will not focus on these aspects of the languages.

2.2 Tasks measuring visual attention (VA) span skills

Two different sets of tasks were used to measure VA span skills in our four studies: either the global and partial report tasks, or the visual 1-back task. They are all presented in the following sections.

2.2.1 Global report and partial report

The visual attention span has been measured in many studies using two main tasks, the global and partial report tasks. These two tasks are used in the second study (page 71) and are presented in the two following sections.



(a) Global report task (b) Partial report task

Figure 2.1: Illustration of the Global and Partial report tasks

The 6-letter strings used in the global and partial report tasks consisted of different combinations of 10 consonants present in the Basque, Spanish and French alphabets (B, P, T, F, L, M, D, S, R, H) without letter repetition within a string. Letter strings were presented on a white background in black uppercase Arial font (height 7 mm and inter-consonant space 0.57°). There were a total of 24 trials in the global report task and a total of 72 trials in the partial report task.

In both tasks, trials began with a central fixation point (1000 ms) followed by a blank screen (50 ms) and the centrally displayed 6-letter string (200 ms). Following the letter string presentation in the global report task, participants were instructed to verbally report as many letters as possible (see figure 2.1a), regardless of order. In the partial report task, the letter string was followed by a single vertical bar, appearing 1.1° below one of the previously presented letters in the string and cueing the participants to report that letter only (see figure 2.1b). In both tasks the experimenter typed the participants' response and proceeded to the next trial by button press without giving feedback. Both tasks were preceded by 10 practice trials during which feedback was provided. In both tasks the dependent measures are typically: the total number or percentage of consonants accurately reported overall or by position. Moreover the average of performance on the two tasks or a composite measure of VA span (performance in global and partial report reduced to the mean number of letters accurately processed at each trial, Awadh et al., 2016) has been used as an individual measure of VA span skills in correlations with reading.

2.2.2 Visual one-back task (VA span)

VA span skills can also be assessed with a visual 1-back paradigm (Lallier et al., 2016). For this paradigm, stimuli were created using 13 consonants present in the Basque, Spanish and French alphabets (B, D, F, G, H, K, L, M, N, P, R, S, T). The consonant strings did not include grapheme clusters corresponding to Basque, Spanish or French phonemes and were not word skeletons of these languages (e.g., T L F N S, for "teléfonos" in Spanish). Letters were not repeated in a single letter string. This paradigm was used in the first (page 47), the third (page 87) and fourth (page 109) studies. Two different tasks were created: a four and a five-consonant string task. Initially (in the first study) the four-consonant task was used for children in earlier grades (particularly 1st grade) since preliminary testing showed that five-consonant strings were too difficult to process for younger children.

The four-consonant string task included 92 different trials and the five-consonant string task included 104 trials. Consonant strings were presented on a white screen in black upper-case Arial font and children were seated 70 cm away from the screen. Stimulus width varied between 4.24° and 4.4° of visual angle (four-consonant task), or 5.3° and 5.55° of visual angle (five-consonant task), and the centre-to-centre distance between each adjacent letter was 1.2° to minimize lateral masking effects. At the start of each trial, a central fixation point was displayed for 1000 ms, followed by the centred consonant string for 200 ms. The consonant string was followed by a white screen lasting 100 ms, and then a single letter (target), appearing below the median horizontal line (see figure 2.2). Target letters were presented in red with a bold-italic font, to reduce visual similarity with the preceding letter strings. Children were instructed to respond as fast as possible by pressing either: a) the "Alt Gr" key (on the right), when the target letter was present in the previously presented consonant string, or b) the "Alt" key (on the left), when the target letter was absent. The target disappeared after the child's response, and a screen with a question mark in the centre was presented, until the experimenter pressed the left mouse button to initiate the next trial. Trial order was randomized.

In the five-consonant task, the 104 trials included 65 trials in which the target was part of the string of consonants (the 13 consonants were presented five times as target, once at each position in the string), and 39 trials in which the target was absent (the 13 consonants were presented three times as targets). In the four-consonant task, the 92 trials included 52 trials in which the target was part of the string of consonants (the 13 consonants were presented four times as target, once at each position in the string), and 40 trials in which the target was absent (the 13 consonants were presented three times as targets and one was presented four times). Both tasks were preceded by five practice trials. Accuracy at each position and for absent trials was recorded, and was used to calculate a sensitivity index (d-prime) that was used in the analysis. Only participants who performed more than 60% of the trials were included in the analysis.

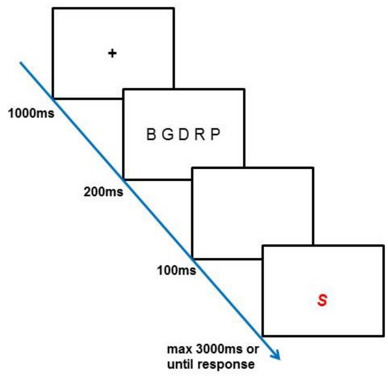
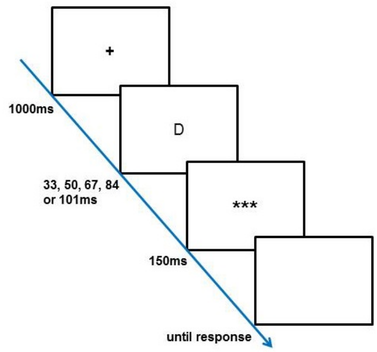


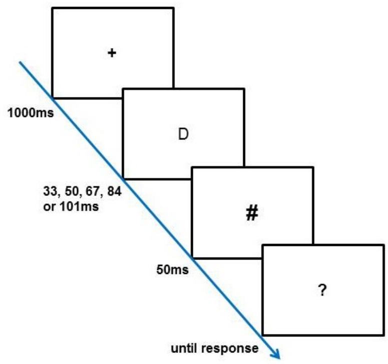
Figure 2.2: Visual 1-back task

2.2.3 Single letter identification

This task is used to assess single element processing, as a control for multi-element processing, measured in the VA span tasks. Trials consisted of presenting each of the consonants used in the global and partial report tasks once for each of five different brief presentation durations (33, 50, 67, 84 and 101 ms). In the single letter processing task that was used with the global and partial report tasks the target letter was followed by a mask for 150 ms (see figure 2.3a). In the single letter processing task that was used with the visual one-back task the target letter was followed by a mask for 50 ms (see figure 2.3b). This difference occurred simply because the tasks were part of different batteries and had been programmed differently. Participants were asked to name the consonant after its presentation. The experimenter typed the participants' response and proceeded to the next trial by button press. At the beginning of the task, participants were presented with 10 practice trials (2 for each presentation time duration) for which they received feedback. This measure was used as a control to the other two VA span tasks in order to identify whether differences between groups or individuals could be related to single as opposed to multi-element processing abilities. A weighted sum, based on the accuracy of letter identification at each presentation duration was computed (accuracy at 33 ms * 5 + accuracy at 50 ms * 4 + accuracy at 67 ms * 3 + accuracy at 84 ms * 2 + accuracy at 101 ms, Awadh et al., 2016; Bosse et al., 2007; Bosse & Valdois, 2009).



(a) Task used with global and partial report



(b) Task used with visual 1-back task

Figure 2.3: Illustration of the single letter processing tasks

2.2.4 Expected pattern of performance on VA span tasks

In most studies on VA span skills and reading, average overall performance is calculated for each individual and associated with reading skills as measured by other tasks. Nevertheless, in some studies the pattern of performance by letter position is analysed and reported (Antzaka et al., 2017; Banfi et al., 2018; Lallier et al., 2016). In these cases, performance on the VA span tasks follows the W-shaped serial position function (although crowding is reduced in the VA span tasks). Thus, briefly explaining the visual constraints that lead to this pattern may be of use to the reader. The W-shaped serial position function is influenced by three main visual constraints: visual acuity, crowding and spatial attention (Grainger et al., 2016).

The W-shaped pattern emerges based on the decrease of acuity from the center of fixation towards the outer letters, and the effect of crowding that decreases the identification of letters that are flanked on both sides more than those flanked on one side. Spatial attention is reflected by the visual span, the number of letters (or words) that can be processed and is dependent on the other factors since a decrease in crowding can increase the visual span (He & Legge, 2017). These visual constraints on reading also evolve with reading development: the visual span becomes asymmetrical to match the direction of reading (we can process more letters to the right of fixation when reading in a left to right script: Nandy & Tjan, 2012) and crowding is decreased for letters as compared to other stimuli as a result of reading expertise (Grainger, Tydgat, & Isselé, 2010; Vejnović & Zdravković, 2015). Studies have also demonstrated that crowding effects, similarly to VA span skills, are related to the development of efficient reading skills (Gori & Facoetti, 2015; Montani, Facoetti, & Zorzi, 2015; Zorzi et al., 2012).

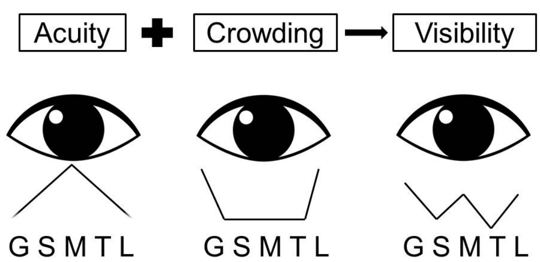


Figure 2.4: W-shaped serial position function. Adapted from Grainger et al. (2016)

Part II

Cross-linguistic studies

Chapter 3

The effect of orthographic depth on visual attention span and rapid automatized naming

3.1 Introduction

As presented in the general introduction, a main theme of this thesis is the study of linguistic and orthographic influences on the size of the orthographic grain used in reading. In the present chapter we will present a cross-linguistic study in developing readers in which we particularly focused on the influence of orthographic depth on orthographic grain size. The modulation of orthographic grain size was measured both with the VA span task, and with a modified version of the rapid automatized naming (RAN) task (presented below). Importantly, the study cross-linguistically compared two groups of children, Spanish-Basque and French-Basque bilinguals, testing both groups in their common language (Basque) while searching for evidence of differences in the orthographic depth of the other language.

As mentioned in the introduction, the concept of orthographic depth encompasses the aspects of complexity and predictability (consistency) of grapheme-to-phoneme mappings (Schmalz et al., 2015). In deep orthographies with more complex grapheme-to-phoneme mappings, readers rely on processing larger orthographic units (Ziegler & Goswami, 2005). When these units are reliable (maintained within different lexical units), the use of these larger orthographic grains leads to successful reading. This study focuses on orthographies in which grapheme-to-phoneme mappings are reliable, but differ in complexity. The aim is to investigate whether acquiring a writing system with complex grapheme-to-phoneme mappings, that leads the reader to rely on larger orthographic units (Schmalz et al., 2016), can favor simultaneous multi-letter processing even in non-reading tasks. We have already discussed how previous literature provides evidence that the effects of orthographic depth can be observed in reading (A. W. Ellis, 2004; Sprenger-Charolles, Siegel, Jiménez, & Ziegler, 2011; Ziegler & Goswami, 2005). The present study takes the novel approach of studying whether the effect of orthographic depth extends to two skills previously linked to reading ability, but that do not directly involve reading: the visual attention span and rapid automatized naming of letters.

The introduction presented the visual attention (VA) span, the number of elements within a multi-element array that can be processed simultaneously (within a single fixation) (Bosse et al., 2007). This component reflects both aspects of visual short term memory and visual processing speed (Lobier et al., 2013), independently of phonological processing (Bosse & Valdois, 2009; Lobier, Zoubrinetzky, & Valdois, 2012; Peyrin et al., 2012; Valdois et al., 2004, but: Ziegler, Pech-Georgel, et al., 2010). The implication of the VA span in reading development has been demonstrated in both shallow and deep orthographies (Bosse et al., 2007; Bosse & Valdois, 2009; Germano et al., 2014; Lallier, Donnadieu, & Valdois, 2013a; Valdois, Guinet, & Embs, 2014; van den Boer et al., 2013). Nevertheless, the aspect of multi-element processing represented by VA span skills, could be of particular significance when at the first stage of reading development it is essential to process larger orthographic units, as is the case in deeper orthographies.

In favour of this view, cross-linguistic studies have demonstrated differences both in VA span skills and their implication in reading, in relation to orthographic depth. More specifically in a study with adult monolingual readers (Awadh et al., 2016), VA span skills were found to correlate with reading skills for readers of French (a deeper orthography), but not for readers of Spanish (a more shallow orthography). Another study investigated letter string processing in English monolingual adults, and in bilingual adults who could also read in the shallow Welsh orthography (English-Welsh bilinguals, Lallier, Carreiras, et al., 2013). The results demonstrated that the latter group showed a disadvantage in rapid processing of multiple letters. This disadvantage was interpreted as a result of the bilingual group's experience reading in a more shallow orthography, that lead to a decrease in the degree of reliance on larger orthographic units in reading (Lallier, Carreiras, et al., 2013). These studies either tested monolinguals of different languages, or compared monolingual to bilingual participants. Only one study has previously compared the VA span skills of bilingual participants reading in a common shallow (Basque), and either a second shallow (Spanish), or deeper (French) orthography (Lallier et al., 2016). This previous study demonstrated marginal differences between the two groups of bilinguals on their VA span skills in a group of early readers. These marginal differences indicated that

French-Basque bilingual children had a wider distribution of visual attention across letter strings, compared to Spanish-Basque bilingual children (Lallier et al., 2016). The present study aims to corroborate and clarify the previous findings regarding the effect of orthographic depth on the VA span skills of bilingual populations, and to investigate possible effects of orthographic depth on rapid automatized naming (RAN).

RAN is indexed by the speed at which an individual can sequentially name a set of visual stimuli (e.g., colours, images of familiar objects, letters: Wolf & Bowers, 1999), and is also related to reading abilities across orthographies differing in orthographic depth (Fleury & Avila, 2015; Furnes & Samuelsson, 2011; Georgiou, Papadopoulos, et al., 2012; Holopainen, Ahonen, & Lyytinen, 2001; Lafrance & Gottardo, 2005; Lervåg & Hulme, 2009; Manis, Seidenberg, & Doi, 1999; Moll et al., 2014; Plaza & Cohen, 2003). The contribution of RAN speed to reading skill has been demonstrated in monolingual (English: Compton, 2003; Cutting & Denckla, 2001; Manis et al., 1999; Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007, Dutch: de Jong & van der Leij, 1999, Italian: Di Filippo et al., 2006, Greek: Georgiou, Papadopoulos, et al., 2012, Finnish: Holopainen et al., 2001; Lepola, Poskiparta, Laakkonen, & Niemi, 2005, Norwegian: Lervåg et al., 2009, German: Moll, Fussenegger, Willburger, & Landerl, 2009, Spanish: López-Escribano, 2012; López-Escribano & Katzir, 2008; Suárez-Coalla, García-de Castro, & Cuetos, 2013, French: Plaza & Cohen, 2003), and bilingual (Brazilian Portuguese/English: Fleury & Avila, 2015,French/English Lafrance & Gottardo, 2005) typically developing readers of various alphabetic orthographies. A RAN deficit has also been linked to cases of dyslexia (Denckla & Rudel, 1976; Di Filippo et al., 2006; Fawcett & Nicolson, 1994; Heikkilä, Närhi, Aro, & Ahonen, 2009; McBride-Chang & Manis, 1996; Wimmer & Mayringer, 2002; Wolf & Bowers, 1999; Wolf, O'Rourke, Gidney, & Lovett, 2002). Although the sub-processes that underlie the RAN-reading relation are debated (for a review see: Norton & Wolf, 2012), we suggest that there is a degree of overlap between the processes involved in performing the VA span and the RAN tasks, and that both tasks involve simultaneous multi-element processing.

Indeed, certain studies support that multi-element processing is a core element of RAN performance. More specifically, some studies have shown that RAN of stimuli presented simultaneously on a stimulus board (serial RAN) explains additional variance in reading fluency after RAN of sequentially presented individual stimuli (discrete RAN) has been taken into account (P. G. Bowers, 1995; Logan & Schatschneider, 2014; Logan, Schatschneider, & Wagner, 2011). Moreover, in serial RAN, studies have demonstrated that while a single stimulus is fixated and processed, effects of neighbouring stimuli can be observed (facilitation or interference in performance: Jones, Ashby, & Branigan, 2012; Jones, Branigan, & Kelly, 2009; Yan, Pan, Laubrock, Kliegl, & Shu, 2013), suggesting parallel processing of multiple elements (see also: Protopapas, Altani, & Georgiou, 2013). The aforementioned studies, in addition to the reported correlations between VA span and RAN performance (van den Boer et al., 2014, 2015), reinforce the hypothesis that both RAN (particularly letter RAN) and VA span involve multi-element processing and should both be modulated by the size of the orthographic units used in reading.

The present study investigates the hypothesis that orthographic depth influences VA span and RAN skills. Both individuals at early and more advanced stages of reading acquisition are included, assuming that the bias towards processing larger orthographic units should increase during reading development, and reflect the shift from sequential decoding of letters to whole word processing (Frith, 1985; Share & Stanovich, 1995). Under this assumption, differences in multi-letter processing abilities attributed to orthographic depth would be more prominent in advanced readers. Moreover, a cross-linguistic approach is taken, studying two groups of bilinguals (i.e., Spanish-Basque and French-Basque bilinguals) in their common language (i.e., Basque). This approach circumvents some methodological limitations of cross-linguistic studies in monolinguals (stimuli choice, language of testing) and offers the additional advantage of the geographical and cultural proximity of these two populations.

The linguistic proximity of the Spanish, French and Basque languages was described in the first section of the second chapter (page 37). As a refresher, it should be noted that Spanish and French are both Romance languages with many similarities, while Basque is an isolated language, descendant of Pre-Indo-European languages (for a review on Basque see Laka, 1996). However, at the level of grapheme-phoneme mappings there is a large overlap between Basque and Spanish. As aforementioned, both the Spanish and Basque orthographies are based on reliable and simple grapheme-phoneme mappings, while French is based on mainly reliable but more complex grapheme-phoneme mappings. Thus, reliance on small orthographic units should suffice for Spanish-Basque bilinguals to read accurately in both languages. On the other hand, when reading in French, French-Basque bilinguals must rely on larger orthographic units. The size of the orthographic units used when reading in Spanish or French are expected to affect reading or reading- related skills of these bilinguals in their other language, meaning Basque, through transfer (Durgunoğlu, 2002; Lallier et al., 2016).

Our specific hypothesis is that: the French-Basque bilinguals will have a wider distribution of visual attention over multiple letters than the Spanish-Basque bilinguals, as a result of learning the more complex grapheme-to-phoneme mappings of the French orthography. This should be reflected in their VA span skills with a more uniform distribution of visual attention over letter strings (Lallier et al., 2016). To capture differences in the distribution of attention over letter strings in RAN, a novel RAN task was designed with the aim of increasing the bias towards processing multiple letters by including letter sequences corresponding to frequent lexical items. The wider distribution of visual attention over multiple letters hypothesized in the French-Basque group, should increase the probability of lexical identification in this group, meaning it should increase the detection of words in the letter sequence. As a result, lexical access from the words' identification should interfere with letter-by-letter naming, thus increasing overall naming speed. Lastly, RAN and VA span skills should correlate positively within both bilingual groups (van den Boer et al., 2014, 2015).

3.2 Methods

3.2.1 Participants

This study included children attending bilingual primary schools (1st–5th grade) in either the French-Basque, or the Spanish-Basque regions of the Basque Country. They were divided into two age groups (younger children from 1st and 2nd grade and older children from 3rd, 4th and 5th grade), depending on whether they had received either fewer or more than 2 years of formal education. This distinction was made because 2 years of formal literacy schooling is usually the limit at which most children have acquired lexical reading successfully (Aaron & Joshi, 1989). From the French-Basque bilingual region, 15 younger children (7 females) and 12 older children (7 females) were assessed, and then matched to children drawn from a larger pool of participants assessed in the Spanish-Basque bilingual region. The project was approved by the ethical committee of the Basque Center on Cognition, Brain and Language.

Children were matched based on gender (all but one pair), chronological age, language background (see below) and two control measures: non-verbal intelligence and text reading fluency in their first language (L1). Language background was matched based on the information collected from the questionnaires the children's (parents or) legal guardians filled in and included: the order of acquisition of their L1 and their second language (L2), the age of acquisition (AoA) of Basque, and the percentage of bilingual exposure (percentage of time exposed to a bilingual environment). Each child's (parent or) legal guardian was informed about the techniques, duration and goals of the study, and provided written consent for the child's participation.

As aforementioned, the two language groups (French-Basque and Spanish-Basque bilinguals) were matched on chronological age within both the younger (U = 123, Z = 0.44, p = .67, r = .08), and older (U = 59, Z = -0.75, p = .47, r = -.15) age groups. Regarding language background, the two language groups were matched on AoA of Basque in the younger (U = 116.5, Z = 0.56, p = .60, r = .10), and the older (U = 98, Z = 1.64, p = .11, r = .33) age groups, and on percentage of bilingual exposure in the younger (U = 61.5, Z = -1.44, p = .16, r = -.26), and older (U = 61.5, Z = 0.066, p = .96, r = .01) age groups. The younger French-Basque bilingual group reported a lower score on overall competence in Basque than the Spanish-Basque bilingual younger group (t = -3.41, df = 21.54, p = .0026). On this measure, no difference was found for the older age groups (t = -0.28, df = 18.38, p = .78, table 3.1). Non-verbal intelligence and text reading fluency are reported in the results section (table 3.2).

Table 3.1: Descriptive statistics on age and language background measures of Spanish-Basque and French-Basque bilingual children

	Younger		**Older**	
	Spanish-Basque (N=15)	**French-Basque** (N=15)	**Spanish-Basque** (N=11)	**French-Basque** (N=11)
Chronological Age				
Mean *(SD)*	6.82 (0.47)	6.88 (0.41)	9.79 (0.98)	9.6 (1.2)
Median	6.75	6.83	9.5	8.96
Range	6.25 - 7.75	6.42 - 7.75	8.58 - 11.17	8.25 - 11.33
Nº children				
L1 Basque	1	1	1	1
L1 Spanish/French[a]	14	14	11	11
Basque AoA (years)[b]				
Mean	2.13 (1.46)	2.32 (1.27)	2.25 (1.14)	3.58 (2.38)
Median	3	3	3	3
Range	0 - 5	0 - 3	0 - 3	0 - 10
% Bilingual exposure				
Mean	31.54 (18.3)	26.79 (29.97)	19.75 (15.39)	29.27 (33.36)
Median	25	15	27.2	20
Range	10 - 80	0 - 100	0 - 40	0 - 80
Basque overall competence(out of 10)				
Mean *(SD)*	7.25 (1.18)	5.52 (1.4)	7.14 (1.32)	7 (0.97)
Median	7.5	5.5	7	6.75
Range	5.25 - 9	3.5 - 7.25	5 - 9.5	5.75 - 8.75

Note. SD: standard deviation. [a] L1 Spanish for the Spanish-Basque and L1 French for the French-Basque bilingual group. [b] AoA=age of acquisition.

3.2.2 Experimental Tasks

3.2.2.1 General Procedure

The tasks presented in this study were administered as part of a larger battery consisting of eight 45-min sessions that were performed with the teachers' permission, during school hours, and in a quiet room within the school. Tasks were carried out in four different orders, and the computer-based tasks were administered using Presentation®. In this study, we focus on VA span abilities and RAN skills. A non-verbal intelligence task and a measure of text reading in the L1 and L2 were used as control tasks. All tasks, except text reading in Spanish or French, were administered and performed in Basque.

3.2.2.2 Cognitive tasks of interest.

Visual attention span (VA span). The visual one-back task (page 41) was used to measure VA span skills. The four-consonant version of the task was used for the younger children (1st and 2nd grade) and the five-consonant version of the task was used for the older children (3rd, 4th and 5th grade) as preliminary piloting showed that five-consonant strings were too difficult to process for younger children (particularly in the 1st grade). Accuracy at each position and for absent trials was recorded on the visual one-back task, and was used to calculate a sensitivity index (d-prime) that was used in the analysis. Only participants who performed more than 60% of the trials were included in the analysis.

The single letter identification task (page 42) was used to assess single element processing, as a control for multi-element processing, measured in the visual one-back task. In this study, performance on the single letter identification task was used to identify children with reduced performance on the task (based on the weighted sum of performance: see page 42).

Rapid automatized naming (RAN). Three letter RAN tasks were administered: consonant RAN, non-word RAN and word RAN (see figure 3.1). In all three tasks, children were presented with a stimulus board on the computer screen. The stimulus board consisted of four rows with nine letters on each row, and children were asked to name each letter as quickly and as accurately as possible. Letters were capitalized and equally spaced in all three tasks. In the typical consonant RAN (figure 3.1a), six consonants were included (G-/ge/, S-/'ese/, M-/'eme/, N-/'ene/, H-/'atʃe /, K-/ka/).The other two RAN tasks included the same letters: four consonants (G-/ge/, S-/'ese/, M-/'eme/, N-/'ene/), and two vowels (E-/e/, U-/u/). The non-word RAN task (figure 3.1b) acted as a control for the word RAN task (3.1c) since it included exactly the same stimuli, with the difference that in the word RAN task, some sequences of letters formed short frequent words in Basque (i.e., "M U S U" = kiss, "U M E" = child, "E G U N" = day, "S E M E" = son, highlighted in figure 3.1d). All these words consist of simple single-letter to phoneme mappings. These Basque words were located at different positions in each row (e.g., starting at the 1^{st}, 3^{rd} or 5^{th} letter of the row). In the non-word RAN task, the letter sequences did not form any words. Note that in all three tasks the same instructions were given: to name the letters one by one as quickly as possible. Children had to name the letters following a direction simulating reading, starting at the top left corner, proceeding in each row from left to right and continuing until the bottom right corner of the stimulus board. Moreover, when the instructions of the word RAN task were given, no indication/clue regarding the hidden manipulation (i.e., the presence of the four Basque words) was provided. Before the test phase in each of the tasks, children were asked to name the individual letters in order to assess their familiarity. Naming speed, which has been commonly linked to reading skills (Landerl & Wimmer, 2008; Manis et al., 1999; Moll et al., 2014), was analysed. RAN tasks were never performed consecutively and the word RAN task was always performed last, in order to avoid that any child who noticed the presence of Basque words would be affected when performing the other RAN tasks.

G K M N H S G S H

H S G K N M N M K

M N H G S K M K G

N H K S M G H N S

(a) consonant RAN

G M U E S U S M N

S N E N G M U E M

E N G U M G S N S

U N S G E M G E U

(b) non-word RAN

G S M U S U E N M

N S N M U M E G E

E G U N M G S N S

U N G S E M E U G

(c) word RAN

G S M U S U E N M

N S N M U M E G E

E G U N M G S N S

U N G S E M E U G

(d) word RAN- words highlighted in blue

Figure 3.1: Illustration of the RAN tasks

3.2.2.3 Control tasks.

Non-verbal intelligence. Non-verbal reasoning skills were assessed using the matrix reasoning subtest of the WISC battery (Fourth edition, Wechsler, 2003), that provides a measure of fluid reasoning. The experimenters coded children's responses during the sessions and their scores were then converted to scaled scores based on chronological age.

Text reading in Basque, French and Spanish. An index of the children's reading level in their L1 and L2 was recorded using a passage from the novel "The Little Prince" ("Printze txikia", "El Principito", "Le Petit Prince", see appendix A, page 181) by Antoine de Saint-Exupéry (used in previous studies: Lallier et al., 2016, 2014). The French passage was taken from the original text, while the Spanish and Basque passages were professional translations that were adapted by native speakers in order to be closer in length to the French original. Versions were matched for the number of lines (n = 9), while the number of words differed slightly ($n_{Spanish}$ = 104, n_{Basque} = 90, n_{French} = 104). Including spaces the French text numbered 614 characters, the Spanish 587, and the Basque 609 characters. Children were asked to read the text aloud, as rapidly and accurately as possible for a maximum of 5 minutes. The individual measure calculated was that of words correctly read per second (w/sec), for each of the texts.

3.2.3 Data Analyses

For most tasks and measures described, Type II ANOVAS (ULL R Toolbox Hernández-Cabrera, 2012) on performance were conducted with language group (French-Basque bilinguals, Spanish-Basque bilinguals) and age group (younger children, older children) as between-subject factors. D-primes on the VA span task were analysed separately for the different age groups, since the younger and older children performed different versions of the task, with language group as a between-subject factor. Additional within-subject factors were included depending on the task: (a) target position for the VA span task (1–4 or 1–5 depending on the task) and (b) task for the different RAN stimuli (consonant RAN, non-word RAN and word RAN). In cases of assumption violations, data transformation, corrections or non-parametric tests were used (i.e., log transformation, p-values based on Greenhouse–Geisser corrections for violation of sphericity assumptions, Mann–Whitney U test, Wilcoxon signed-rank test). Post hoc comparisons were performed using the least square means contrasts (lsmeans package: Lenth, 2016)[1] and adjusting the p-values with Hochberg corrections. Plots and tables always report the untransformed data for simplicity. Finally, Pearson correlations between individual scores of overall naming speed (sec) on the RAN tasks and the average d-prime scores on the VA span task, were performed within each of the language groups, controlling for chronological age and age-standardised non-verbal intelligence.

3.3 Results

3.3.1 Control Tasks

The ANOVA on the age-standardised non-verbal intelligence scores showed no significant main effect or interaction ($ps > .70$), indicating that the French-Basque and Spanish Basque bilinguals were matched on this measure. The ANOVA on log-transformed reading fluency in the L1 (French or Spanish) also showed no effect or interaction with language group ($ps > .29$), indicating that the two language groups were matched on their reading skills in their L1. However, there was an effect of grade ($F(1,48) = 49.40, p < .0001, \eta_p{}^2 = .51$), with the older age group being more fluent than the younger age group. The ANOVA on log-transformed reading fluency in Basque (L2) showed a main effect of language group ($F(1,48) = 21.77, p < .0001, \eta_p{}^2 = .31$) and no interaction with age group ($p > .53$), indicating that overall the Spanish-Basque bilingual group read more Basque words per second than the French-Basque bilingual group. Moreover, the main effect of age group ($F(1,48) = 40.54, p < .0001, \eta_p{}^2 = .46$) indicated that the older age group overall read more words per second in Basque than the younger age group (table 3.2).

[1]The article derived from this data used pair-to-pair contrasts for the post hoc tests. Nevertheless the use of this alternative has been suggested to provide better control over Type I error. We thus changed all tests for the thesis. Results either maintained the same pattern of significance or became more conservative (the latter only in the case of the RAN analysis). Nevertheless the main results that were discussed in the article remained the same.

Table 3.2: Descriptive statistics on the non-verbal intelligence and text reading tasks for Spanish-Basque and French-Basque bilinguals

	Younger		Older	
Control tasks	**Spanish-Basque** (N=15)	**French-Basque** (N=15)	**Spanish-Basque** (N=12)	**French-Basque** (N=12)
Non-verbal intelligence (age stand.)				
Mean *(SD)*	11.8 (2.91)	11.47 (3.11)	11.25 (2.6)	11.5 (2.75)
Median	11	11	11	12
Range	8 - 19	6 - 17	8 - 15	7 - 15
Basque text reading (w/sec)				
Mean *(SD)*	0.62 (0.21)	0.37 (0.22)	1.26 (0.34)	0.79 (0.29)
Median	0.61	0.32	1.19	0.68
Range	0.36 - 1.2	0.06 - 0.92	0.95 - 2.14	0.38 - 1.3
Spanish/French text reading (w/sec)				
Mean *(SD)*	0.79 (0.28)	0.73 (0.53)	1.79 (0.59)	1.84 (0.76)
Median	0.78	0.55	1.53	1.76
Range	0.43 - 1.51	0.17 - 2	1 - 3.03	0.76 - 3.25

Note. SD: standard deviation.

3.3.2 Experimental tasks

3.3.2.1 VA span tasks and single letter identification

Single letter identification. No effect of language group was found on the weighted sum, calculated based on performance on the single letter identification task, in the younger (U = 124, Z = 0.48, p = .65, r = .09) or the older children (U = 71, Z = -0.06, p = .97, r = -.01). Subsequently, differences between the two groups on the visual one-back task cannot be attributed to differences in single letter processing (table 3.3).

Table 3.3: Descriptive statistics for single letter identification task for the older and younger Spanish-Basque and French-Basque bilinguals

Age group	Language group	Single letter identification (weighted sum) Mean *(SD)*	Median	Range
Younger				
	Spanish-Basque (*N*=15)	12.39 (1.67)	12.08	9.08 - 14.67
	French-Basque (*N*=15)	12.57 (2.38)	13.21	6.21 - 15
Older				
	Spanish-Basque (*N*=12)	14.15 (0.83)	14.44	12.54 - 14.92
	French-Basque (*N*=12)	14.11 (1.2)	14.44	10.42 - 14.92

Note. SD: standard deviation.

Four consonant visual one-back (younger age group). D-prime sensitivity scores on the VA span task are presented in table C.2 for both the four and five-consonant tasks. An odd-even split was used to determine the split-half reliability of the average d-prime, yielding a coefficient of 0.72. In the younger group, data were transformed to improve the distribution and homogeneity of variance by moving all scores within the positive range (by adding the absolute value of the smallest score to all the data), and then applying a square root transform. In the younger age group there was no significant effect of language group ($F(1,26) = 2.94$, $p = .10$, $\eta_p^2 = .10$) on d-prime sensitivity in the visual one-back task. There was a significant effect of position ($F(3,78) = 5.50$, $p = .006$, $\eta_p^2 = .17$), but no language group by position interaction ($F(3,78) = 1.19$, $p = .32$, $\eta_p^2 = .04$). The post hoc comparisons on position indicated that d-prime sensitivity was significantly higher on the first than on the third ($\beta = 0.19$, $t = 2.59$, $p = .046$) and the fourth positions ($\beta = 0.27$, $t = 3.80$, $p = .002$), and significantly higher on the second position than on the fourth position ($\beta = 0.19$, $t = 2.65$, $p = .046$), while the differences between sensitivity on other positions were not significant ($ps > .25$, see figure 3.2).

Table 3.4: Descriptive statistics on VA span sensitivity scores for the older and younger Spanish-Basque and French-Basque bilinguals

Age group	Language group		D-prime sensitivity scores by position 1	2	3	4	5	Average d-prime sensitivity
Younger								
	Spanish-Basque (N=14) [a]	Mean *(SD)*	1.22 (1.19)	1.25 (0.93)	0.74 (0.67)	0.65 (0.77)		0.96 (0.59)
		Median	1.19	1.42	0.69	0.5		1.15
		Range	-0.42 - 4.65	0 - 2.91	-0.28 - 1.84	-0.17 - 2.51		-0.14 - 1.72
	French-Basque (N=14) [a]	Mean *(SD)*	1.83 (0.84)	1.23 (0.55)	1.32 (0.93)	0.98 (0.72)		1.34 (0.61)
		Median	1.85	1.34	1.57	0.98		1.31
		Range	0.66 - 3.17	0.15 - 2.05	-0.06 - 0.91	-0.13 - 1.99		0.35 - 2.28
Older								
	Spanish-Basque (N=12)	Mean *(SD)*	1.04 (1.06)	1.55 (0.85)	1.67 (1.02)	0.56 (0.88)	0.77 (0.88)	1.12 (0.81)
		Median	1.29	1.3	1.45	0.43	0.36	0.96
		Range	-1.06 - 2.75	0.36 - 2.9	0.14 - 3.61	-0.71 - 2.07	0 - 2.75	-0.03 - 2.68
	French-Basque (N=12)	Mean *(SD)*	1.67 (0.73)	1.55 (0.72)	1.59 (0.99)	1.11 (0.72)	1.5 (0.83)	1.49 (0.64)
		Median	1.65	1.67	1.82	1.22	1.68	1.5
		Range	0.56 - 3.03	0.53 - 2.46	-0.17 - 3.36	-0.12 - 2.12	-0.17 - 2.95	0.22 - 2.39

Note. SD: standard deviation. [a]. One participant from the Spanish-Basque group and their match from the French-Basque group were removed because the former was only pressing one response button.

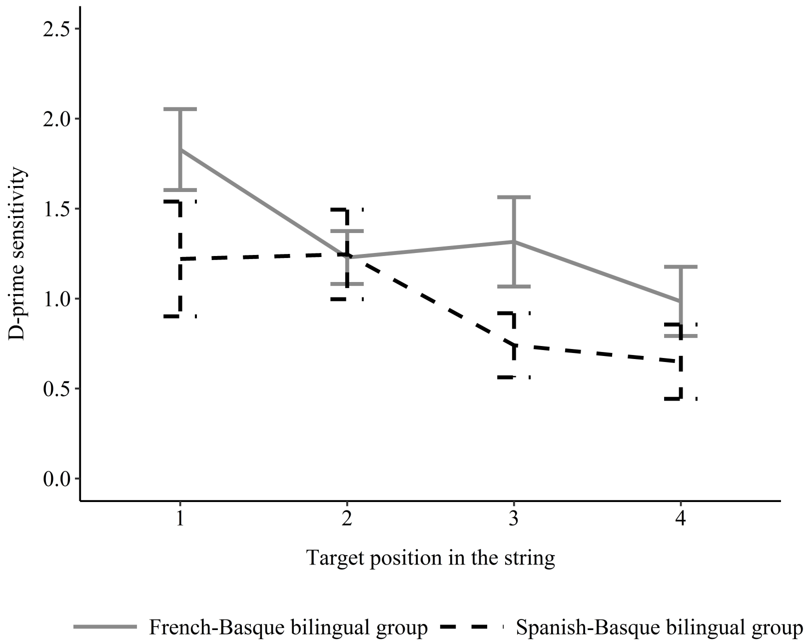


Figure 3.2: D-prime sensitivity scores and standard error bars (1 SE) by position and language group for the four-consonant VA span task performed in the younger age group (1st and 2nd grade children)

Five-consonant visual one-back (older age group). In the older age group there was no effect of language group (F(1,22) = 1.49, p = .24, η_p^2 = .06), but there was a significant effect of position (F(4,88) = 8.85, $p < .001$, η_p^2 = .29), and a language group by position interaction (F(4,88) = 2.99, p = .04, η_p^2 = .12). The post hoc tests did not show differences between the French-Basque and Spanish-Basque bilingual groups on each individual position ($ps > .23$). For the French-Basque bilingual group, d-prime scores were similar across all positions ($ps > .18$). However, for the Spanish-Basque bilingual group, d-prime scores were marginally lower on the first than on the third position (β = -0.63, t = -2.89, $p = .08$), significantly higher on the second than on the fourth position (β = 0.99, t = 4.55, $p < .001$), and significantly higher on the second than on the fifth position (β = 0.78, t = 3.61, $p = .009$). Scores were also higher on the third position than on the fourth (β = 1.11, t = 5.10, $p < .001$) and fifth positions (β = 0.90, t = 4.16, p = .0013, see figure 3.3). No other differences were significant ($ps > .29$). Overall, the results revealed that d-prime sensitivity was stable across all positions for the French-Basque bilingual group, while this was not the case in the Spanish-Basque bilingual group.

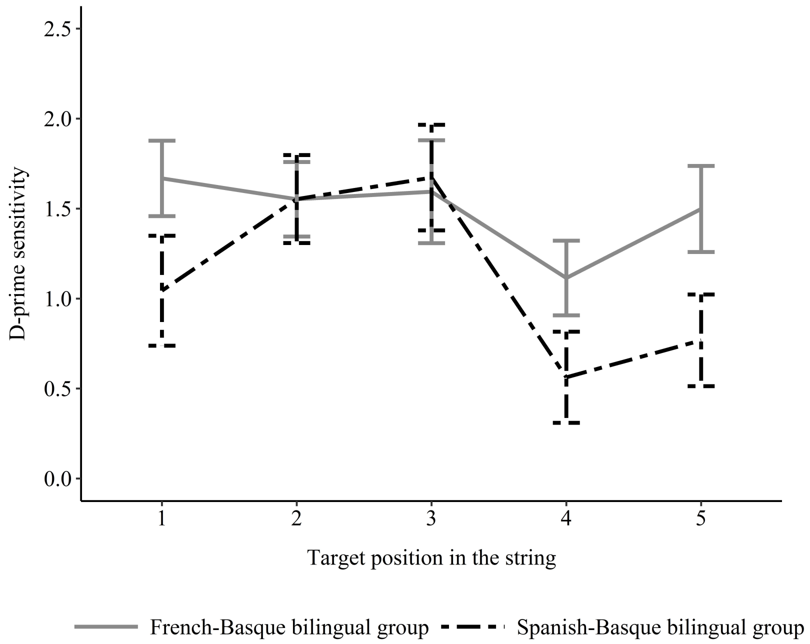


Figure 3.3: D-prime sensitivity scores and error bars (1 SE) by position and language group for the five-consonant VA span task performed in the older age group (3^{rd}, 4^{th} and 5^{th} grade children)

3.3.2.2 RAN tasks.

Descriptive statistics on RAN performance (errors and speed) are presented in table C.3. There were no differences in errors during the RAN tasks in the older (*ps* > .15) or the younger (*ps* > .12) age group (indicating that differences in reaction times are not related to a speed-accuracy trade-off). In naming speed, there was a marginal age group effect ($F(1,48) = 3.92, p = .05, \eta_p^2 = .08$), a significant language group effect ($F(1,48) = 98.06, p < .001, \eta_p^2 = .67$) and a significant task effect ($F(2,96) = 4.01, p = .03, \eta_p^2 = .08$). All these effects were also part of a triple interaction described below. The age group by language group interaction was not significant ($F(1,48) = 0.08, p = .78, \eta_p^2 = .002$). The age group by task ($F(2,96) = 7.63, p = .003, \eta_p^2 = .14$), language group by task ($F(2,96) = 4.75, p = .02, \eta_p^2 = .09$) and age group by language group by task ($F(2,96) = 6.77, p = .005$) interactions were significant.

Table 3.5: Descriptive statistics on speed and errors during the RAN tasks for the older and younger Spanish-Basque and French-Basque bilinguals

		Measure	RAN task Consonant	Non-word	Word
Younger					
Spanish-Basque (N=15)	Speed	Mean *(SD)*	30.73 (6.17)	27.79 (5.08)	25.61 (4.69)
		Median	31.43	25.03	25.28
		Range	22.1 - 43.05	22.8 - 37.28	19.37 - 36.13
	Errors	Mean *(SD)*	0.8 (1.57)	0.73 (1.22)	0.27 (0.46)
		Median	0	0	0
		Range	0 - 6	0 - 4	0 - 1
French-Basque (N=15)	Speed	Mean *(SD)*	96.52 (53.2)	76.88 (48.64)	80.03 (64.83)
		Median	81.51	61.23	55.69
		Range	44.8 - 224.79	29.13 - 173.32	25.91 - 216.53
	Errors	Mean *(SD)*	2.33 (2.99)	1.87 (3.02)	1.4 (2.35)
		Median	1	0	0
		Range	0 - 8	0 - 9	0 - 7
Older					
Spanish-Basque (N=11)[a]	Speed	Mean *(SD)*	19.5 (5.43)	18.18 (3.6)	17.86 (4.82)
		Median	20.66	18.31	19.83
		Range	11.37 - 29.6	12.37 - 23.85	9.45 - 26.33
	Errors	Mean *(SD)*	0 (0)	0 (0)	0 (0)
		Median	0	0	0
		Range	0 - 0	0 - 0	0 - 0
French-Basque (N=11)[a]	Speed	Mean *(SD)*	49.84 (22.44)	36.83 (8.99)	128.51 (67.51)
		Median	41.16	37.8	122.09
		Range	25.2 - 101.21	23.31 - 49.28	29.55 - 247.74
	Errors	Mean *(SD)*	0.27 (0.9)	0 (0)	0.18 (0.4)
		Median	0	0	0
		Range	0 - 3	0 - 0	0 - 1

Note. SD: standard deviation.[a]. One outlier from the French-Basque group and their match from the Spanish-Basque group were removed due to a technical issue during assessment (RAN speed>700sec).

The post hoc tests[2] indicated that the younger children of the French-Basque bilingual group performed similarly on all the RAN tasks ($ps > .98$). The younger children of the French-Basque bilingual group also performed both the consonant RAN ($\beta = 46.68$, $t = 3.35$, $p = .005$) and the non-word RAN ($\beta = 40.05$, $t = 2.87$, $p = .02$) tasks more slowly than the older French-Basque bilingual group, but performed the word RAN task ($\beta = -48.48$, $t = -3.48$, $p = .004$) faster than the older French-Basque bilingual group. The older children in the French-Basque bilingual group performed both the consonant and non-word RAN at a similar speed ($\beta = 13.00$, $t = 0.87$, $p = .98$), while performance on the word RAN task was slower than in both of these tasks (consonant RAN-word RAN comparison: $\beta = -78.68$, $t = -5.26$, $p < = .001$, non-word RAN-word RAN comparison: $\beta = -91.69$, $t = -6.13$, $p < = .001$).

The post hoc tests also indicated that the younger children of the Spanish-Basque bilingual group performed all tasks at a similar speed ($ps > .98$) and the same was true for the older children of the Spanish-Basque bilingual group ($ps > .98$). Moreover, the younger children of the Spanish-Basque bilingual group did not performed the RAN tasks significantly more slowly than the older children of the Spanish-Basque bilingual group ($ps > .57$). Lastly, the Spanish-Basque bilinguals performed most RAN tasks more quickly than the French-Basque bilinguals of the same age group ($ps < .001$, see figure 3.4). There were two cases in which differences between the two language groups were not significant, both occurred in the older age group: in the older age group the Spanish-Basque bilingual group was marginally faster than the French-Basque bilingual group on the consonant RAN ($\beta = 30.34$, $t = 2.03$, $p = .09$), and there were no significant differences between the two groups on the non-word RAN task ($\beta = 18.64$, $t = 1.25$, $p = .21$).

Overall, the RAN tasks tended to be performed faster by the older than by the younger age group although differences were only significant fro the French-Basque bilingual group. Moreover, the French-Basque bilingual group performed most RAN tasks more slowly than the Spanish-Basque bilingual group. Of particular interest is the pattern of performance found for the word RAN task in the French-Basque bilingual group: while there was no effect of the manipulation in the younger age group, in the older age group the word RAN task was performed more slowly than

[2]The assumption of normality was violated in two of the sub-conditions and could not be corrected by transforming the data. Initially, all post-hoc comparisons were also performed using the Mann-Whitney U and Wilcoxon signed-rank tests and adjusting for multiple comparisons. The pattern of significance remained the same so the parametric ANOVA and post hoc comparisons were presented in the article derived from this data for simplicity. Nevertheless, using least square means contrasts we found that results were more conservative and considered they would be preferred over pair to pair tests.

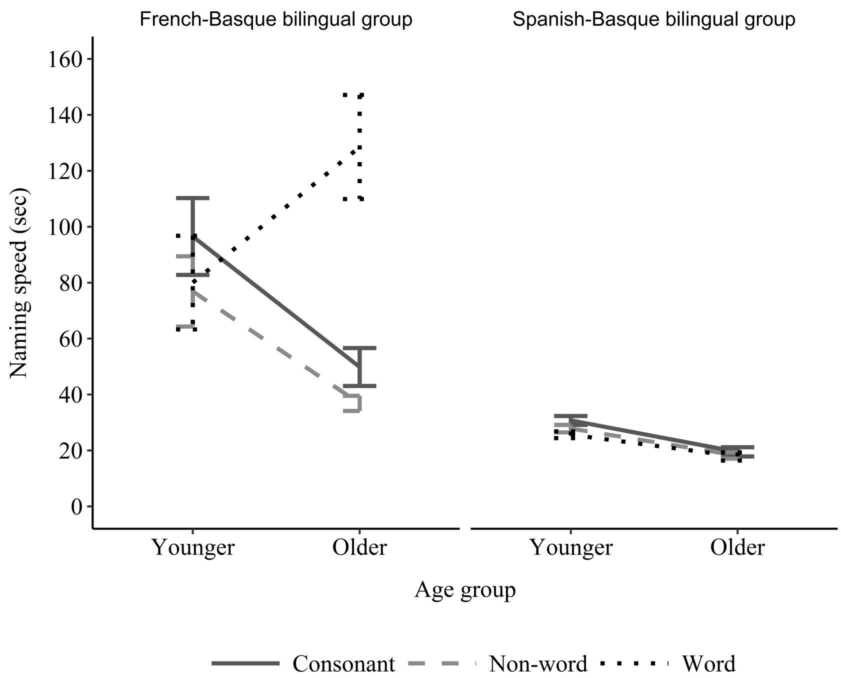


Figure 3.4: Mean speed of naming and standard error bars (1 SE) of performance on the RAN tasks by language group and by age group

the two other RAN tasks by the French-Basque bilingual group. This pattern of results was absent in the Spanish-Basque bilingual group.

3.3.2.3 Correlations between RAN and VA span performance.

Correlations were performed between the average d-prime scores on the VA span task and the reaction times of the RAN task. Although the latter were not normally distributed, correlations performed using the normally distributed, log transformed data, resulted in the same patterns of significance. Thus, correlations and plots present the untransformed data (see table 3.6 and figure 3.5) for simplicity. No significant correlations were found between performance on any of the RAN tasks and the VA span task, neither in the Spanish-Basque bilingual group ($ps > .24$), nor the French-Basque bilingual group ($ps > .16$). However, note that the direction of the correlations in the French-Basque bilingual group indicated that: better VA span skills related to better performance on RAN in the consonant and non-word RAN tasks, while the opposite was true in the word RAN task (possibly because in the latter, better multi-element processing resulted in easier identification of the embedded words).

Table 3.6: Pearson's r scores of partial correlations between scores on the RAN and VA span tasks for each of the two language groups (Spanish-Basque and French-Basque bilinguals) including younger and older children

Language group (N=25)	**RAN task**		
	Consonant	**Non-word**	**Word**
Spanish-Basque	-0.06	-0.17	-0.02
French-Basque	-0.30	-0.30	0.26

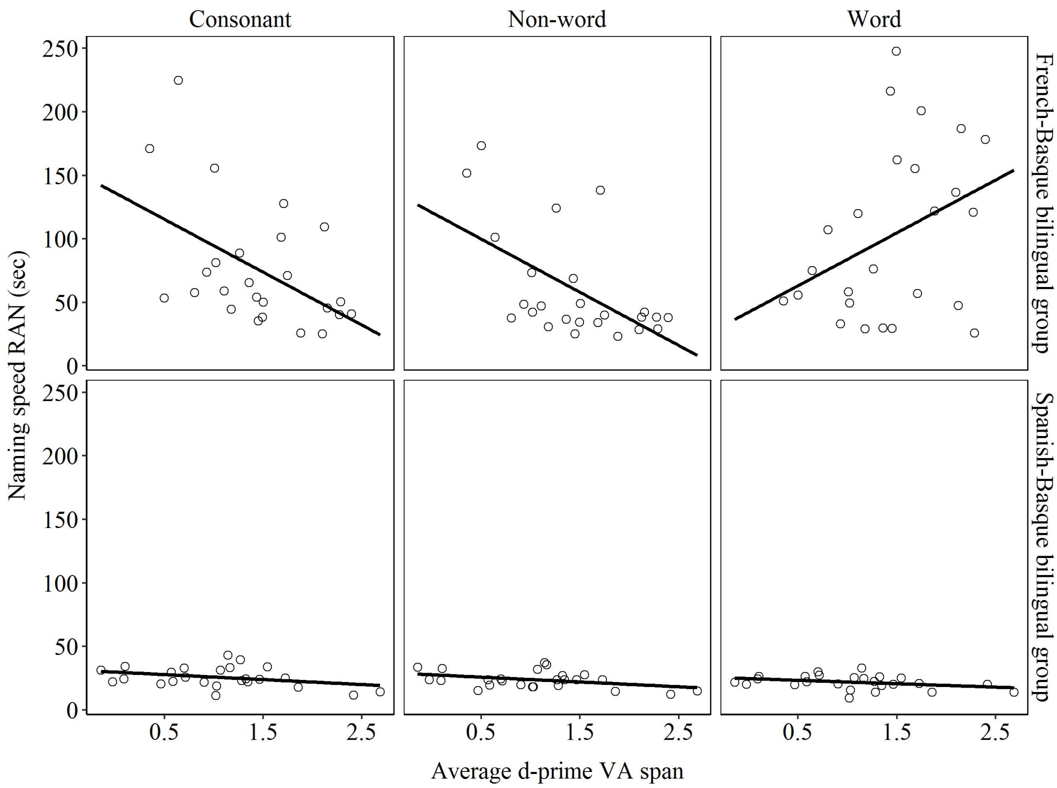


Figure 3.5: Plot of correlations between RAN speed (sec) and average d-prime sensitivity within each RAN task and language group. The plot presents original scores. Control variables are not accounted for in the plot.

3.4 Discussion

The present study investigated the performance of French-Basque and Spanish-Basque bilinguals on two tasks requiring visual letter processing, namely the visual attention span (VA span) and rapid automatized naming (RAN) of letters. The hypothesis was that the influence of reading in the deeper French orthography would result in French-Basque bilinguals being more biased towards processing larger multi-letter units than Spanish-Basque bilinguals. This difference was expected to be observed both in VA span skills and the RAN task including frequent words.

The results in both the RAN and VA span tasks demonstrated no significant differences in the pattern of performance of the French-Basque and Spanish-Basque bilinguals in the earlier grades. This should result from children still relying strongly on sequential decoding at these early stages of reading acquisition. As mentioned in the introduction, the shift towards whole-word processing in later stages of reading acquisition (Frith, 1985; Share & Stanovich, 1995), and the subsequent use of larger orthographic units, should enhance the observable effects of orthographic depth on the size of multi-letter units that are processed. However, previous studies have reported effects of orthographic depth in first and second grade children both in phonological processing skills (Bialystok, Majumder, & Martin, 2003; Goswami, Ziegler, & Richardson, 2005; Mann & Wimmer, 2002; Patel et al., 2004), and visual or orthographic processing skills (Kandel & Valdois, 2006; Lallier et al., 2016). Therefore the possibility that differences can be observed earlier in reading development given either more sensitive measures, or larger sample sizes, cannot be discarded.

Interestingly, despite the lack of significant differences in the younger group, there were indications that in both tasks multi-letter processing was relied on to a greater extent in the French-Basque bilingual group. Regarding VA span skills, the pattern of results demonstrated, even in the younger children, higher average d-prime sensitivity for the French-Basque as compared to the Spanish-Basque bilinguals. Furthermore in the RAN task including words, the experimenter reported that even in the younger group, only children from the French-Basque bilingual group read out loud some of the words hidden in the stimulus board (4 of the 15 children of the younger group and 8 of the 11 children of the older group of French-Basque bilinguals).

The above trends favour the previous explanation: that the lack of effects in younger children is related to the earlier stage of reading acquisition, which undermines the effects of orthographic depth. More specifically regarding the lack of effects in RAN in the younger group, it has been suggested that the developmental transition from more sequential or item-by-item processing to more parallel processing (involving processing of more items at a time) is characteristic of reading but is also reflected in RAN (Protopapas et al., 2013). If this is the case, in more advanced readers RAN processing should involve processing more letters at a time, thus providing a better setting to observe the interference of the words introduced in the task. A final possibility is that the influence of words in the RAN task was reduced in the younger French-Basque bilinguals due to their lower level of Basque proficiency. However, given that the words included in the task were highly frequent, this is a less plausible explanation.

Importantly, in both the VA span and RAN tasks, the results in the older group of children supported the initial hypotheses. Concretely, the results on VA span sensitivity in the older group of children indicated that the French-Basque bilinguals distributed their attention more uniformly across the letter string, since sensitivity was similar on all five positions. This was not the case for the Spanish-Basque bilinguals, who were significantly less sensitive to the final letters of the string (4^{th} and 5^{th} as compared to the 2^{nd} and 3^{rd} letters), and marginally less sensitive to the initial than the central position (where the children were fixation). The uniform distribution of attention in the French-Basque bilinguals is attributed to their experience reading in the French orthography, which is characterised by more complex grapheme-to-phoneme mappings. The complexity of these mappings results in the use of larger orthographic units in reading, and is reflected in their ability to process more letters with similar sensitivity. These results are also in agreement with previous findings highlighting the VA span as a useful index of the influence of orthographic depth on visual letter processing (Awadh et al., 2016; Lallier et al., 2016; Lallier, Carreiras, et al., 2013).

Concerning the RAN results, the insertion of high frequency Basque words in the task had a detrimental effect only in French-Basque bilinguals of the older group. The slower naming scores of the French-Basque bilinguals in this task can be interpreted as the manifestation of a processing cost resulting from lexical access to the Basque words. According to this hypothesis, French-Basque bilingual children in the older group must have processed more letters in parallel when performing the task than their Spanish-Basque peers, thus capturing the letters that composed the Basque words as a whole. These results confirm that the effects of orthographic depth can be observed in tasks not directly involving reading (Lallier et al., 2016; Lallier & Carreiras, 2018). Furthermore, the results indicate that there is a degree of multi-letter processing in the RAN that can be enhanced under certain conditions (in this case the insertion of lexical units). This supports previous studies suggesting that there is an aspect of multi-element processing in RAN (P. G. Bowers, 1995;

Logan & Schatschneider, 2014; Logan et al., 2011; Protopapas et al., 2013), and could explain the previously reported correlations between VA span and RAN performance (van den Boer et al., 2014, 2015).

One of the issues that arise from the RAN results is that of the slower performance of the French-Basque bilingual group in most cases (the non-word RAN task in the older group being the exception). Two factors could explain this result: a) while the two groups were matched on most language background measures, Spanish-Basque bilinguals were overall more fluent in Basque text reading, b) the degree of overlap in the pronunciation of letter names is almost complete between Spanish and Basque but smaller between French and Basque (e.g., the letter "H" is pronounced /ˈatʃe / in both Spanish and Basque but /aʃ/ in French), thus increasing the difficulty of the task for the French-Basque bilinguals. Notably, this overall difference should not result from other group differences, since age, non-verbal intelligence and reading in the L1 were matched. Moreover, this should not jeopardize the main result, that the older group of French-Basque bilinguals was slower on the word RAN as compared to the other RAN tasks.

In general, one of the limitations of this study is the small sample size that did not allow matching the groups on some variables such as overall competence and reading fluency in Basque. However, the small sample size and lower Basque proficiency of the French-Basque bilinguals are factors that decrease the possibility of encountering the observed effects. Therefore, studies on larger samples that are more extensively matched on language measures should demonstrate even stronger effects.

The third hypothesis exposed in the introduction, was that RAN and VA span performance should correlate within both French-Basque and Spanish-Basque bilinguals. No correlations were found in either group. The lack of correlations between VA span and RAN skills was not expected based on previous studies (van den Boer et al., 2014, 2015, also see Jones et al., 2008). To address the possibility that the lack of correlation was due to the small sample size, the larger pool of participants assessed in the Spanish-Basque bilingual region (260 children from grades 1 to 5) was used to study the relation between these two skills. Significant correlations between average VA span sensitivity (d-prime) and RAN speed were found for all three tasks, while controlling for age and age-standardised non-verbal intelligence, (consonant RAN: r = -.20, p = .001; non-word RAN: r = -.18, p = .004; word RAN: r = -.20, p = .001), indicating that sample size was indeed a factor affecting the results and that, overall, better VA span skills relate to faster RAN.

Another aspect to consider when examining the results in the word RAN task is that of individual differences in RAN processing. The hypotheses and results support that RAN performance reflects multi-letter processing and that the number of letters that can be processed is influenced by orthographic depth. If this is the case, reading experience in deep orthographies should increase the bias towards multi-letter processing, while reading experience in shallow orthographies should decrease this bias. For the Spanish-Basque bilinguals, reading more in either of the two shallow orthographies would not create heterogeneity in this bias, since reading in either of the two orthographies should decrease the bias towards multi-letter processing. However for French-Basque bilinguals, children who read more in the deep French orthography would be more strongly biased towards multi-letter processing than children who read more in the shallow Basque orthography. Therefore within the French-Basque bilinguals, the degree to which each individual is biased towards multi-letter processing could be more variable and depend on the time spent reading in each language[3]. Differences in the degree of bias towards multi-element processing as a result of the amount of time spent reading in a deep or shallow orthography would also be expected to influence the multi-element processing bias reflected by VA span skills.

Chapter Summary

The results indicate that reading in the deep French orthography led to a larger bias towards the use of multi-letter processing in both the VA span and the word RAN tasks in more advanced readers (3rd, 4th and 5th grade). Further research on larger samples is needed to test the degree to which orthographic depth and bilingual reading experience can affect the bias towards multi-letter processing depending on the relative time spent reading in each language. Cross-linguistic studies at this level can provide information regarding the difficulties faced by bilingual children learning to read in two languages, but also regarding the tools they have at hand to compensate for these difficulties.

[3]While the information necessary to answer this question was available for the sample of this study, the results were not conclusive due to the small variability of reading experience in Basque for the French-Basque bilinguals.

Chapter 4

The visual attention span in skilled reading: effects of language orthography and morphology

4.1 Introduction

The data presented in the previous chapter support the influence of orthographic depth on orthographic grain size, as reflected by visual attention (VA) span skills. The aim of the present study was to further investigate factors that could lead to the modulation of the orthographic grain size in reading, and thus of the VA span and its role in reading in alphabetic orthographies.

In the present study, we focused on skilled readers of the three previously presented languages with alphabetic orthographies: Spanish and Basque (both consistent orthographies) and French (more complex, slightly less consistent)[1]. We tested both their reading skills and their VA span. Based on previous studies comparing the VA span skills of readers of more and less consistent orthographies (and on the results of the previous chapter) we expected that the French group would either have better VA span skills and/or that their VA span skills would be more strongly related to reading (Lallier et al., 2016; Lallier & Carreiras, 2018; Lallier, Carreiras, et al., 2013). We also expected that any differences between the Basque and the Spanish group could not be attributed to orthographic depth and would be related to other language differences. As presented in the second chapter (page 37), some aspects of Basque that could lead to differences in the role of the

[1]The data of the L1 French and the L1 Spanish group were collected in order to be included in (Awadh, 2016) and published in Awadh et al. (2016)

VA span in reading are: a) the prominence of morphological units in Basque, that suggests attention to multiple units within a word may be more important and require enhanced visual processing skills, b) the presence of longer words in text as a result of Basque's agglutinative morphology and, c) the, regarding many aspects, head-final structure of the Basque language that could enhance attention to elements present at the end of word (e.g., postpositions).

4.2 Methods

4.2.1 Participants

Participants were 18-45 years old, either university students/graduates or were receiving/had received professional training. The study was approved by the local ethics committee at the Université Grenoble-Alpes and at the Basque Center of Cognition, Brain and Language. All participants provided informed written consent. Participants tested in Spain formed two language groups based on their first language (L1): the L1 Spanish and L1 Basque group. Participants recruited in France formed one group based on their L1: the L1 French group. Three participants were removed from the L1 French group because they were native speakers of both French and another language, disrupting the homogeneity of the group. Overall in all language groups participants had knowledge of a second language (mostly English in the L1 French group and Basque, Spanish or English in the L1 Spanish and Basque groups). For the L1 Basque and L1 Spanish groups self-reported language background information was available on the recruitment database as were vocabulary scores (de Bruin, Carreiras, & Duñabeitia, 2017). We used this information to avoid recruiting balanced bilinguals. Two participants were removed from the L1 Basque group since their low Basque vocabulary scores indicated they were not fluent native speakers. The three groups of participants did not differ significantly on chronological age ($F(2,111) = 0.59$, $p = .56$, $\eta_p^2 = .01$, see table 4.1 for descriptive statistics).

Table 4.1: Descriptive statistics on chronological age

	L1 Spanish (n=42, F=32)	**L1 Basque** (n=36, F=26)	**L1 French** (n=36, F=31)
Mean *(SD)*	22.26 (2.26)	21.58 (2.62)	22.61 (6.36)
Median	22	21	21
Range	19-29	18-31	18-45

Note. SD: standard deviation.

4.2.2 Experimental Tasks

Visual attention span tasks. Global and partial report tasks (page 40) were used to measure the VA span, together with the single letter identification control task (page 42). The order of these tasks was counterbalanced across participants and the single letter control task was always administered between the global and partial report tasks. The dependent measures of the global and partial report tasks were the percent correctly reported consonants per position that were compared across language groups, and a composite measure of VA span (performance in global and partial report reduced to the mean number of letters accurately processed at each trial: weighted sum of performance, see page 42) that was used to calculate correlations with reading.

Text reading tasks. Depending on their L1, participants were presented with either a Basque, Spanish or French text on an A4 sheet of paper. For the L1 Basque and L1 Spanish participants, those who could also read the text in the other language (i.e., all L1 Basque participants could read the Spanish text, and 17 L1 Spanish participants could read the Basque text) read both texts (since this was not the main focus of the study, these results are presented in brief). The Spanish text on climate change was chosen from the newspaper “El Mundo”, the Basque text on electronic cigarettes from the newspaper “Elhuyar”, and the French text that was descriptive and reported an artistic experience in Moscow in the twentieth century was from the newspaper “Le Monde”[2]. The aim was to use texts that were similar in difficulty and length, including proper names. Texts were not matched on formal measures. Participants read the text aloud for a maximum of 3 minutes. An individual measure of reading ability, namely words correctly read per minute, was used in the analyses. Very few errors were made so they were not reported.

4.2.2.1 General Procedure

Participants were tested individually in a quiet dimly lit room in a single session. Order of testing was counterbalanced.

4.2.3 Data Analyses

Group differences on text reading and single letter identification were tested using Type II ANOVAs with L1 (Spanish, French, Basque) as the between-subject

[2] The Basque text is presented in appendix B, page 185. The Spanish and French texts can be found in the Supplementary material of Awadh et al. (2016).

factor. The global and partial report tasks were analysed using Type II ANOVAs (ULL R Toolbox, Hernández-Cabrera, 2012) with language group as a between-subject factor, and letter position as a within-subject factor. In cases of assumption violations, either data transformation, corrections (e.g., Greenhouse-Geisser corrections for violation of sphericity assumptions), or non-parametric tests (e.g., Wilcoxon signed-rank test, Spearman correlation) were used. Post hoc comparisons were performed using least square means contrasts (Lenth, 2016). In the case of the global and partial report scores, which violated normality assumptions, particularly on letter positions in which performance was high, ANOVAs were used since they are robust to violations of normality. Nevertheless, the results of post-hoc comparisons were also tested using non-parametric alternatives (Mann-Whitney U and Wilcoxon signed-rank tests). Correlations between VA span and reading scores were tested using Pearson correlations. Hochberg corrections were applied to groups of post hoc comparisons and correlations.

4.3 Results

4.3.1 Text Reading skills

Reading scores were logarithmically transformed to reduce differences in the distribution of values between the language groups. Comparisons between the groups on reading in the L1 cannot be considered informative regarding the groups reading skills since the materials were not formally matched. Reading fluency in the L1 significantly differed between participants ($F(2,111) = 53.11, p < .0001, \eta_p^2 = .49$). The post hoc comparisons indicated that the L1 Spanish group read significantly more words correctly per minute than the L1 Basque group ($t = 9.86, p < .0001$) and marginally more than the L1 French group ($t = 1.88, p = .06$). The L1 French group also read significantly more words per minute than the L1 Basque group (t= 7.69, p < .0001). Descriptive statistics on text reading are presented in table 4.2.

4.3.2 Single letter identification skills

The French data on single letter identification were lost due to technical problems. The L1 Basque and L1 Spanish group did not differ significantly on their ability to process single letters as measured by the weighted composite score of single letter identification threshold ($U = 793.5, Z = 0.47, p = .64, r = 0.05$). Descriptive statistics on single letter identification are presented in table 4.2.

Table 4.2: Descriptive statistics on text reading in the L1 Spanish, L1 Basque and L1 French group

	L1 Spanish (n=42, F=32)	**L1 Basque** (n=36, F=25)	**L1 French** (n=36, F=31)
Text Reading L1			
Mean *(SD)*	167.43 (25.31)	125.14 (15.24)	157.53 (15.77)
Median	163.33	124.33	156.50
Range	118 - 225	89 - 155.33	118.33 - 192.67
Single Letter Identification			
Mean *(SD)*	147.48 (5.87)	148 (3.25)	NA
Median	150	150	NA
Range	120 - 150	140 - 150	NA

SD: standard deviation. *Only 17 of the L1 Spanish participants read the text in Basque (N = 17).

4.3.3 Visual Attention Span Tasks

Descriptive statistics on performance on the VA span tasks are presented in table 4.3.

Table 4.3: Descriptive statistics on VA span skills by letter position in the L1 Spanish, L1 Basque and L1 French group

			Average letter identification by position					
			1	**2**	**3**	**4**	**5**	**6**
L1 Spanish								
	Global	Mean *(SD)*	96.98 (8.23)	92.4 (12.62)	94.06 (6.03)	78.33 (17.88)	62.5 (22.63)	79.9 (16.69)
		Median	100	95.83	95.83	83.33	66.67	85.42
		Range	50 - 100	33.33 - 100	70.83 - 100	20.83 - 100	12.5 - 95.83	25 - 100
	Partial	Mean *(SD)*	92.06 (13.77)	74.6 (20.41)	91.47 (10.96)	89.48 (12.08)	75.79 (19.81)	76.79 (19.78)
		Median	100	83.33	91.67	91.67	75	83.33
		Range	41.67 - 100	41.67 - 100	50 - 100	50 - 100	16.67 - 100	25 - 100
L1 Basque								
	Global	Mean *(SD)*	99.54 (1.33)	97.8 (2.9)	96.3 (5.61)	82.29 (14.48)	61.57 (18.9)	73.15 (19.93)
		Median	100	100	100	87.5	62.5	79.17
		Range	95.83 - 100	91.67 - 100	79.17 - 100	41.67 - 100	25 - 91.67	8.33 - 100
	Partial	Mean *(SD)*	94.21 (8.64)	81.48 (17.72)	93.98 (8.59)	91.9 (8.56)	76.16 (16.2)	82.64 (17.41)
		Median	100	83.33	100	91.67	83.33	91.67
		Range	66.67 - 100	33.33 - 100	66.67 - 100	66.67 - 100	41.67 - 100	41.67 - 100
L1 French								
	Global	Mean *(SD)*	97.57 (3.05)	95.49 (6.09)	93.75 (7.94)	73.84 (15.96)	56.6 (23.56)	76.62 (18.64)
		Median	100	95.83	95.83	75	56.25	81.25
		Range	91.67 - 100	75 - 100	70.83 - 100	37.5 - 100	12.5 - 100	25 - 100
	Partial	Mean *(SD)*	89.12 (14.88)	66.2 (21.91)	90.28 (11.87)	85.42 (18.51)	65.74 (21.43)	79.4 (18.63)
		Median	91.67	66.67	91.67	91.67	66.67	83.33
		Range	41.67 - 100	16.67 - 100	58.33 - 100	25 - 100	16.67 - 100	33.33 - 100

SD: standard deviation. *Two participants were removed from the L1 Spanish group because they missed a trial on the global report task.

Global report. Two participants were removed from the L1 Spanish group because they missed a trial on the global report task. The Type II ANOVA showed an effect of target letter position ($F(5,545)$ = 164.96, p <.0001, η_p^2 = .76), no effect of language group ($F(2,109)$ = 0.89, p = .42, η_p^2 = .02), and a marginal target letter position by language group interaction ($F(10,545)$ = 1.95, p = .08 , η_p^2 =.07, see figure 4.1). Post hoc comparisons were performed using both parametric and non-parametric tests on the marginal interaction. The parametric and non-parametric alternatives did not coincide for all target letter positions and language group comparisons questioning the reliability of the interaction. We therefore focus on the post hocs on target letter position. According to the parametric tests, performance was similar on the 1st, 2nd and 3rd positions (*ps* > .16), and better on these than on all other positions (*ps* < .0001) Performance was also similar on the 4th and 6th positions (p = .65) and better on these positions than on the 5th position (*ps* < .0001). The non-parametric tests showed the same pattern of results with the exception of performance on the 1st letter position, which was better than on all other positions (*ps* < .0001).

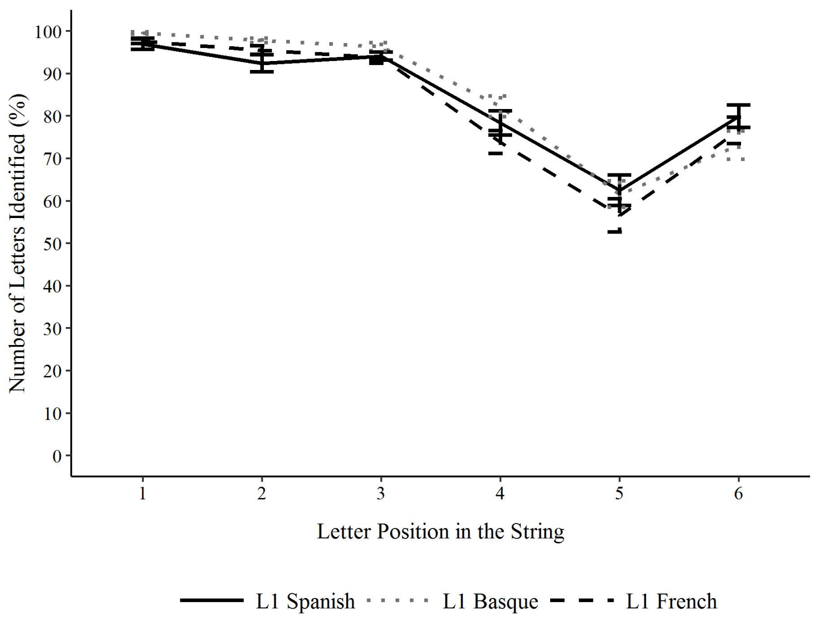


Figure 4.1: Global report task. Letter identification by position and language group. Error bars represent 1 SE.

Partial report. The Type II ANOVA showed a main effect of target letter position ($F(5,555)$ = 44.40, p <.0001, η_p^2 = .66, see figure 4.2) and an effect of language group ($F(2,111)$ = 4.99, p = .008, η_p^2 =.08). Post hoc comparisons on the target letter position effect indicated that letters were identified equally accurately on the 1st, 3rd and 4th positions (*ps* > .38), and that performance on these positions was significantly more accurate than on the 2nd, 5th and 6th positions (*ps* < .0001). Letters were also identified similarly accurately on the 2nd and 5th positions (p = 0.83) and less accurately than on the 6th position (*ps* < .05). The non-parametric post-hoc comparisons on target letter position also showed a similar pattern with the exception of the comparison between performance on the 2nd and 6th positions that according to the non-parametric tests was similar (p = .26). The post-hoc comparisons on the effect of language group only showed a significant difference between the L1 Basque and L1 French groups with the L1 Basque responding overall more accurately than the L1 French (β = 7.37, t = 3.16, p = .006, other *ps* = .14). The non-parametric tests showed the same pattern of results for the L1 comparisons.

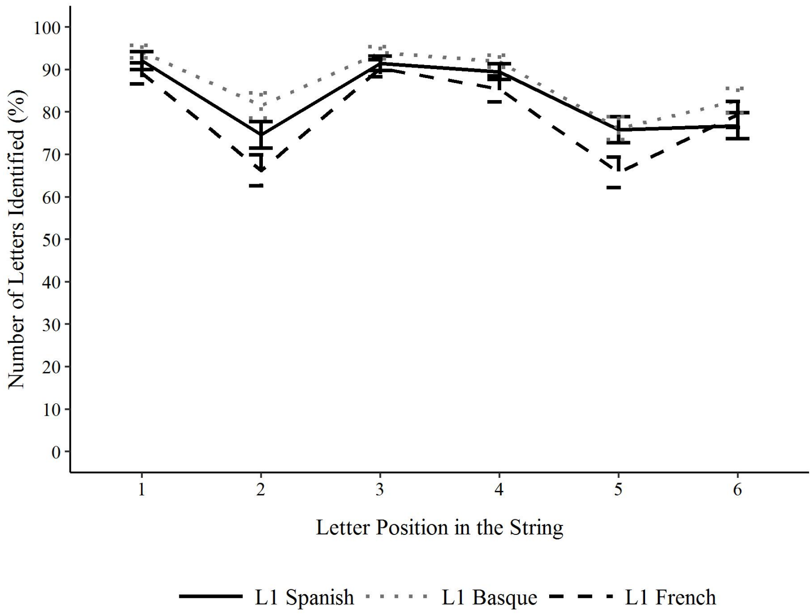


Figure 4.2: Partial report task. Letter identification by position and language group. Error bars represent 1 SE.

4.3.4 Correlations between VA span and text reading performance

For each language group, Pearson partial correlations were performed between a composite measure of VA span (performance in global and partial report reduced to the mean number of letters accurately processed at each trial, Awadh et al., 2016) and text reading performance in the L1 (wpm), while controlling chronological age (in years) and for the weighted sum of single letter identification performance (the latter for the L1 Basque and L1 Spanish groups). The two participants from the L1 Spanish group who missed a trial in the global report task were also removed from the correlation analysis. There was no significant correlation between text reading in the L1 and VA span skills for the Spanish group (N = 40, r = -.06, p = .72), but correlations were significant for both the Basque (N = 36, r = .41, p = .047) and the French groups (N = 36, r = .38, p = .047, see figure 4.3)[3].

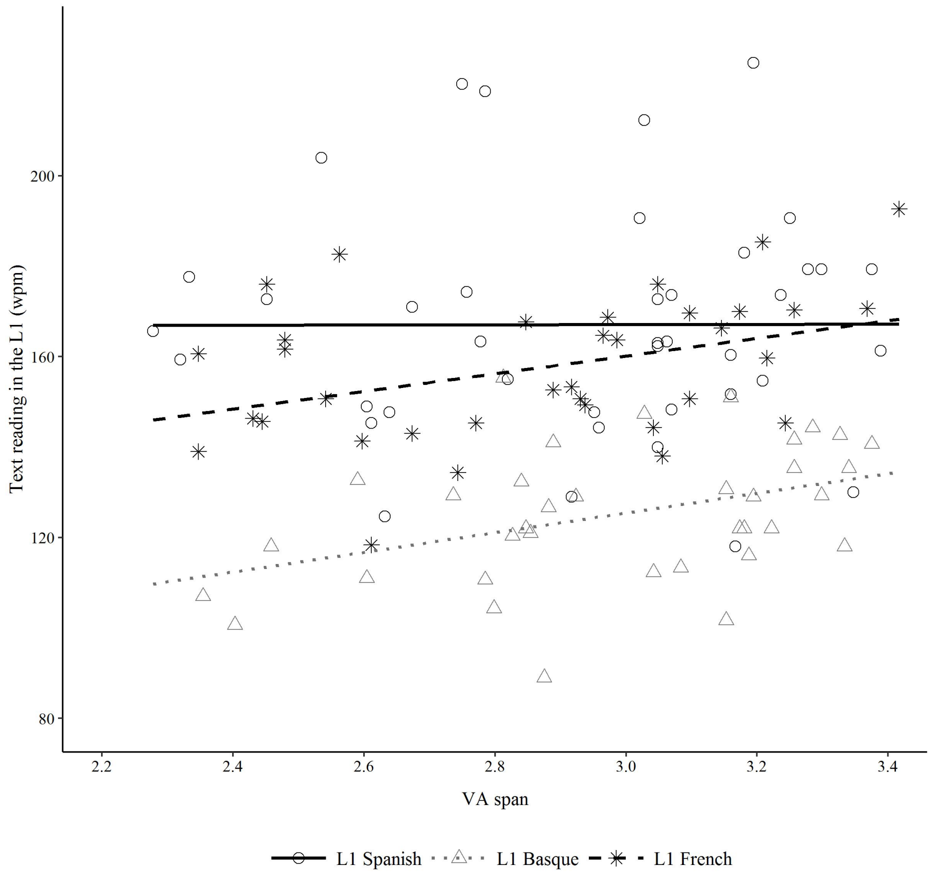


Figure 4.3: Correlations between VA span and text reading speed in French, Spanish and Basque. The plot presents original scores. Control variables are not accounted for in the plot.

[3]Similar patterns were found in the Spanish and Basque groups for reading in the second language: no correlation for the L1 Spanish group (N = 16, r = .19, p = .53), and a marginal correlation for the L1 Basque group (N = 36, r = .36, p = .07).

4.4 Discussion

The present study aimed to investigate the VA span skills of adult individuals reading in three alphabetic orthographies (Spanish, Basque and French), and the possible link between their VA span and reading skills. The three groups showed similar patterns of letter identification performance on both the global and partial report tasks, although the L1 Basque group performed overall more accurately than the L1 French group on the partial report task. Regarding text reading skills both the L1 Spanish and French groups read more words correctly per minute than the L1 Basque group. Finally, correlations between VA span and text reading skills were found in the L1 Basque and the L1 French group, but not in the L1 Spanish group. The results are discussed more extensively in the following paragraphs.

4.4.1 Text reading skills in the L1 Basque, Spanish and French groups

According to the analysis of text reading skills in the L1, the L1 Spanish and French groups performed similarly and read more words per minute than the L1 Basque group. Given that the text reading material was different in each language group, we cannot clearly disentangle whether this result reflects differences in the reading fluency of the participants or text and language-related differences. Nevertheless, when comparing reading in Spanish of the L1 Basque (who could all read the Spanish text) and the L1 Spanish groups no differences were found (t = 0.61, df = 74.78, p = .54). Therefore, differences are more likely to be related to language or text-related factors. One aspect that could have led to these differences is that the average number of letters per word in the Basque text ($n_{lettersperword}$ = 7.18) was higher than in the Spanish ($n_{lettersperword}$ = 5.29), and French texts ($n_{lettersperword}$ = 5.30), as expected given that Basque is an agglutinative language (Öney & Durgunoğlu, 1997).

4.4.2 VA span skills in the L1 Basque, Spanish and French groups

Similar patterns of letter identification performance were found for all groups in the global and partial report tasks, although the L1 Basque group performed overall more accurately than the L1 French group on the latter task. The similar pattern of performance indicates that deployment of attention across consonant strings arises based on the same constraints in readers of all three languages. This is expected for readers of alphabetic orthographies that are read from left to right.

More specifically, in the partial report task performance reflects constraints on letter visibility (for a review: Grainger et al., 2016), acuity (the distance from fixation) and crowding (the space surrounding the letter), that lead to the typical

W-shaped serial position function. Performance on the global report task follows the same constraints but is modulated by a stronger left-to-right bias in performance related to reading direction (Awadh et al., 2016, also in optimal viewing position paradigms: Brysbaert & Nazir, 2005; Brysbaert, Vitu, & Schroyens, 1996; Nazir, Heller, & Sussmann, 1992). The stronger reading direction bias results from the higher short term memory demands of the global as compared to the partial report task. Importantly this bias arises despite participants being instructed to report as many consonants as possible regardless of the position in which they appeared in the string.

Better performance of the L1 Basque as compared to the L1 French group in the partial report task is inconsistent with previous results suggesting that readers of less consistent orthographies (i.e., L1 French group) are more efficient at processing more letters in parallel (Ktori & Pitchford, 2008; Lallier & Carreiras, 2018; Lallier, Carreiras, et al., 2013) due to their bias towards processing larger orthographic grains and their greater reliance on lexical processing (Ziegler & Goswami, 2005). Nevertheless, the smaller bias towards larger orthographic grains and towards lexical processing may lead readers of less consistent orthographies to be similarly efficient at both lexical and sub-lexical processing, as indicated by a study on readers of Italian (Ripamonti, Luzzatti, Zoccolotti, & Traficante, 2018), possibly making them more efficient at processing individual letters within a string. The aforementioned study used the Reicher-Wheeler paradigm, which similarly to the partial report task, relies on efficient letter position coding[4]. This is not the case in the tasks used in studies showing the opposite pattern of results (i.e., enhanced letter processing for readers of less consistent orthographies: Antzaka et al., 2018; Ktori & Pitchford, 2008; Lallier et al., 2016; Lallier, Carreiras, et al., 2013). We thus suggest that differences in orthographic consistency and the bias towards lexical and sub-lexical processing may modulate visual aspects of orthographic processing in opposite directions: for example readers of less consistent orthographies may tend to process more letters in parallel but be less sensitive to relative letter position coding (also supported by coarse grain orthographic processing not encoding absolute letter position: Grainger & Ziegler, 2011). Indeed in our study the differences between the L1 Basque and French groups tended to be larger in the more crowded positions of the string, in line with studies suggesting that crowding effects also result from decreased letter position coding sensitivity (Collis et al., 2013; Pelli, Palomares, & Majaj, 2004). Nevertheless, the reduced differences in other letter positions could also be a result of ceiling

[4]The influence of the aspect of letter position coding on partial report performance is also highlighted by the results of Holmes and Dawson (2014) who found that performance on the task was correlated with the detection of letter misorderings in words.

effects. The results of a recent study on Arabic are also in line with the idea that the bias towards lexical processing in reading could increase sensitivity to crowding (Lallier et al., 2018).

4.4.3 Correlations between VA span skills and text reading in the L1 Basque, Spanish and French groups

VA span skills were linked to text reading in the L1 French and the L1 Basque group but not in the L1 Spanish group. The presence of a correlation in the L1 French but not the L1 Spanish group has previously been attributed to differences in orthographic depth (Awadh et al., 2016), suggesting that while VA span skills may be important for reading development in both languages (Bosse & Valdois, 2009; Onochie-Quintanilla et al., 2017; Valdois, Peyrin, et al., 2014), their importance may decrease in fluent readers of Spanish due to the consistency of the orthography. Nevertheless, the presence of the VA span-reading link in the L1 Basque adults raises questions regarding this interpretation since Basque is also a consistent orthography. It could be the case that orthographic depth is not the only factor modulating the VA span-reading link and/or that in adult reading VA span skills may be less related to aspects of single-word reading and more related to aspects of multi-word processing. A similar developmental shift has been suggested for the link between rapid automatized naming and reading (Protopapas et al., 2013). If this is the case, and VA span skills in adult reading are more linked to multi-word processing, text reading in Basque could tax VA span skills more highly than text reading in Spanish due to the agglutinative nature of the orthography that leads to, on average, longer words.

We suggest that the agglutinative nature of Basque characterises it as an outlier orthography, despite its orthographic consistency. Evidence in favour of this interpretation is provided by cross-linguistic studies investigating the contribution of classical reading predictors to reading skills in a variety of alphabetic orthographies including Finnish, another consistent agglutinative alphabetic orthography. In one study (Landerl et al., 2013), phonological awareness was highlighted as the strongest predictor of both reading speed and accuracy in most languages. However in Finnish, vocabulary was the strongest predictor of reading speed and both vocabulary and phonological awareness predicted reading accuracy. In another study (Moll et al., 2014), rapid automatized naming was found to be the strongest predictor of reading speed in all languages but in Finnish in which its role was similar to that of two other phonological predictors (also see: Ziegler, Bertrand, et al., 2010). Moreover, in the same study the overall variance in reading speed that could be explained based on all the predictors was lower in Finnish than in the other studied languages (also see:

Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012). It could be the case that in Finnish, similarly to Basque, the consistency of the orthography and the agglutinative nature decrease the importance of classical predictors of reading and attribute more importance to other skills, possibly more related to oral language comprehension (e.g., vocabulary or morphological awareness). This is also supported by the data presented in the next chapter in which we show that while VA span skills are related to fluent reading in Basque developing readers (i.e, related to lexicality effects) they do not correlate to overall reading speed for individual items.

The absence of a correlation between word reading and VA span skills in developing readers of Basque (next chapter) is inconsistent with the presence of a correlation between VA span skills and text reading in adult readers of Basque (this chapter). However, we once again consider that this might be related to the VA span reflecting visual attention demands of single word reading during reading development and multi-word reading in skilled readers. If so, it could be that in Basque, although VA span skills support reading they are less related to the speed of single word reading but are still associated to the speed of multi-word processing. Moreover, the influence of VA span skills on Basque multi-word processing (i.e., text reading), could be particularly evident in adult readers that have already acquired sight word reading for most words and are therefore more likely than developing readers to be processing more than one word in parallel when reading text. The agglutinative nature of Basque and the subsequent length of the words could then tax visual attention resources more heavily and lead to the observed correlations between text reading and VA span skills in Basque but not Spanish.

Chapter Summary

Overall our results indicate that patterns of letter identification performance in adult readers of alphabetic orthographies are similar and follow the expected W-shaped pattern of sensitivity. Thus, in skilled readers of alphabetic orthographies VA span skills may not reflect difference in orthographic grain size. Nevertheless, the difference in overall performance of the L1 Basque as compared to the L1 French group in the partial report task suggests that although readers of more inconsistent orthographies may be able to process more letters in parallel, readers of more consistent orthographies may have finer letter position coding sensitivity. Further work would be needed to support this hypothesis. Finally, the correlations between reading and VA span skills in the L1 French and L1 Basque group indicate that in skilled readers differences in orthographic grain size may: a) still be reflected by the role of VA span skills in reading, and b) may result from the influence of language factors beyond orthographic depth. More specifically, we consider orthographic grain size and subsequently the role of VA span skills in reading may also depend on agglutination and subsequent word length or other factors characterising a language's morphology.

Part III

Studies in Basque

Chapter 5

The visual attention span and the morphological structure of orthographic stimuli

5.1 Introduction

The previous chapter introduced the idea that morphological structure could influence orthographic grain size and subsequently the role of the VA span in text reading cross-linguistically. In the present study we will shift our focus towards morphological structure at the word (rather than the text) level and to reading within a single language, Basque.

As presented in the introduction, word identification can proceed either based on the coarse or the fine grain route of orthographic processing (Grainger & Ziegler, 2011). The coarse-grained route facilitates processing at the lexical level, optimizing word identification. The alternative fine-grained route reflects processing of multi-letter patterns at the sub-lexical level; allowing the identification and construction of relevant orthographic units of multi-letter graphemes, frequent letter combinations and morphemes. In the course of reading development, the use of these two routes, paired with the influence of language-specific orthographic constraints, gives rise to specific grapheme-to-phoneme mapping strategies. These strategies support the internalization of recurring letter patterns and their pronunciations, thus paving the way towards fluent reading. Both the coarse and the fine grained routes of reading require parallel letter processing (Grainger, 2017), which could be one of the mechanisms underlying the reported link between visual attention and reading (Bosse et al., 2007; Franceschini et al., 2012; Vidyasagar & Pammer, 2010).

Of particular relevance to this thesis is the particular link between VA span skills and the ability to process larger orthographic grains, facilitating their recognition and internalization. More specifically, we mentioned in the introduction that the VA span has been related to the acquisition of lexical orthographic representations (Bosse et al., 2013) and to orthographic knowledge, spelling and copying skills (Bosse et al., 2014; van den Boer et al., 2015). Moreover, a larger VA span favours reading accuracy of irregular words (for which whole-word processing is essential) more strongly than that of regular words or pseudowords (Bosse & Valdois, 2009). Finally, a reduced VA span has been associated with poor word – as opposed to pseudoword - reading abilities in certain developmental dyslexia profiles (Bosse et al., 2007; Peyrin et al., 2011, 2012; Valdois et al., 2003; Valdois, Guinet, & Embs, 2014). Thus, the VA span likely modulates the degree to which essential orthographic grains are internalized during reading development.

Based on the above, research thus far suggests that both lexicality (word versus pseudoword), and the consistency of grapheme-to-phoneme mappings (irregular versus regular words) can modify orthographic grain size and thus the strength of the contribution of VA span skills to reading. In the same vein, orthographic depth (the complexity and regularity of grapheme-to-phoneme mappings in a given language-orthography combination) was also found to be a significant modulator of the VA span-reading relationship, with a stronger relationship for deep orthographies – that include irregular words and complex graphemes– than shallow orthographies (Lallier & Carreiras, 2018, for a review). The results presented in chapters 3 and 4 support the latter finding.

In the present study, we wanted to study whether the morphological status of larger orthographic units could also modulate the salient orthographic grain size in reading and thus the contribution of VA span skills. Concretely, we wanted to determine whether the presence of morphemes - a key recurrent multi-letter orthographic grain with a semantic representation – in words would change the strength of the VA span-reading relationship. The present study will aim to examine this question. In order to do so, we will focus on derivational morphology in Basque (Acha et al., 2014; Laka, 1996). As presented in chapter 2, Basque is a morphologically rich agglutinative (head-final) language, in which most words are morphologically complex. Although derivational morphemes affect meaning, whilst inflectional morphemes affect syntax, both are highly productive and are stacked at the end of the stem, leading to the formation of long, morphologically complex words. These characteristics have led to particular interest in morphological processing in this language (e.g., Duñabeitia et al., 2009, 2007), and evidence suggests that morpheme internalization is attained very early during reading development (Acha et al., 2010). Importantly for this study, Basque, similarly to Spanish or Italian, has a shallow orthography, thus eliminating the confounding factor of orthographic depth in the modulation of grain size.

Summarising the studies presented in the introductory section on morphemes in reading (page 28), studies on the effects of derivational morphology on reading in shallow orthographies show a “morphological benefit”: an advantage for reading items including sub-lexical morphemes over items that are morphologically simple. The benefit is attributed to the fact that morphemes act as a large sub-lexical grain or reading unit that is processed more easily than its constituent letters and graphemes (Burani, 2009; Burani et al., 2008). Interestingly, this morphological benefit is particularly evident when the coarse grain route is likely to fail, since it occurs when naming morphologically complex pseudowords (Angelelli et al., 2014; Burani et al., 2008, 2002; Suárez-Coalla & Cuetos, 2013; Traficante et al., 2011), or low frequency words (Angelelli et al., 2014; Burani et al., 2008; Marcolini et al., 2011; Traficante et al., 2011, but Alessio et al. 2018 reported the benefit in both high and low frequency words), as well as for less expert and dyslexic readers who have not fully developed their lexical reading procedure (Burani et al., 2008; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013).

Overall, the aim of the present study was twofold. First, we sought to investigate whether a morphological benefit would be visible across development when naming morphologically complex Basque words (e.g., “egunkari”- newspaper) and pseudowords (e.g., “anbalkari”) as compared to morphologically simple items (e.g., “adiskide”- friend, “ispareku”); to this end we assessed the naming skills of Basque speaking children attending the 2nd and 4th grade in a cross-sectional design. Based on the aforementioned studies in shallow orthographies, a morphological benefit in naming was especially expected when the coarse grain route fails, namely on pseudoword naming, for both age groups, and possibly on word naming in the 2nd grade, since beginning readers have access to fewer lexical orthographic representations (Ehri, 2005; Frith, 1985; Share & Stanovich, 1995). Second, we wanted to determine whether the presence of sub-lexical morphemes in the items would influence the VA span-reading relationship, which we interpret as a measure of the orthographic grain size used in reading. To this purpose, we also assessed the VA span skills of these children. We reasoned that if the presence of sub-lexical morphemes provides an intermediate grain for reading (smaller than the lexical grain for words and larger than the grapheme or syllable for pseudowords), it should influence multi-letter processing demands, and thus VA span demands. More specifically, we predicted that the influence of VA span skills on naming would be modulated by the potential benefit the processing and identification of larger as compared to smaller orthographic grains could provide in naming the presented item. Thus we expected a stronger influence of VA span for naming morphologically simple words as compared to morphologically simple pseudowords. For morphologically complex words we hypothesized that if children are sensitive to morphemes in these stimuli, the presence of an accessible intermediate grain could decrease effects of VA span skills on word naming performance. Finally, for morphologically complex pseudowords a larger VA span could allow the processing of the real morpheme within the unfamiliar stimulus, thus providing a larger benefit than in the case of morphologically simple pseudowords.

5.2 Methodology

5.2.1 Participants

Children in the 2nd and 4th grades of primary school education in the Spanish-Basque region of the Basque Country, Spain, participated in this study. All children were native speakers of Basque with Spanish as a second language. Language background information was acquired through a questionnaire completed by the child's (parent or) legal guardian. Seven children whose L1 was not Basque were removed from the analysis, leaving 27 children in the 2nd and 30 children in the 4th grade. Teaching was in Basque with only courses on English and Spanish language taught in the respective languages. Each child's (parent or) legal guardian was informed about the techniques, duration and goals of the study and provided written consent for the child's participation. The project was approved by the ethical committee of the Basque Center on Cognition Brain and Language.

5.2.2 Experimental Tasks

5.2.2.1 Morphological Processing Task: Naming

Stimuli. Stimuli consisted of 160 six- to nine-letter items that were manipulated at two different levels: lexicality (words vs. pseudowords) and morphological complexity (simple vs. complex items). The stimuli included 80 words and 80 pseudowords, half of which were morphologically simple (consisting of a single morpheme), while the other half were morphologically complex (consisting of two morphemes). Morphologically simple words consisted of a single morpheme (e.g "*panpina*"-doll), while morphologically complex words consisted of a stem with a derivational suffix (e.g "*margol**ari***"-painter). Pseudowords were composed of legal letter combinations and were matched with words on average bigram token frequency and length. Morphologically complex pseudowords were constructed based on the morphologically complex words of the stimulus list (see below), maintaining either the real derivational suffix or the real stem of the word and using either a pseudo-stem or pseudo-suffix (e.g. "*ent**zain***", "***sega**zare*"). Although most previous studies constructed morphologically complex pseudowords using an unreal combination of a real stem and a real suffix, some studies have found subtle but facilitative effects when using pseudo suffixed pseudowords (pseudostem + real suffix) compared to simple pseudowords, particularly in accuracy (Colé et al., 2012; Traficante et al., 2011). Selecting such a conservative manipulation (with either a real stem or a real suffix) could a) enhance sublexical reading in pseudowords compared to words b) avoid facilitative effects derived from substitution neighbours and ensure that any facilitative effect obtained in the morphologically complex pseudoword set was due to the recognition of a significant regularity, stem or suffix. Additionally, since it has been suggested that pseudowords formed by a real stem + pseudosuffix could also lead to facilitative effects (Traficante et al., 2011), we included both the pseudostem + suffix and stem + pseudosuffix stimuli to examine whether any difference in reading accuracy would be found between these two types of morphologically complex pseudowords.

Regarding the morphologically complex word stimuli, although morphological facilitative effects are more prone to appear in low frequency words (Deacon et al., 2011), the high productivity of Basque allows Basque children to benefit from suffixes present in high frequency words even from third grade, at least with regard to inflectional morphology (Acha et al., 2010). Thus we decided to include both low and high frequency words (half of each set of words: morphologically complex and simple). Moreover, half of the morphologically complex words (within both the high and low word frequency stimuli), had high stem frequency while the other half had low stem frequency. Given that this is the first study on reading morphologically complex words studying developing readers in Basque, we performed an additional analysis only on the morphologically complex words in order to investigate the effects of word and stem frequency on reading speed and accuracy.

Both for the word and the pseudoword stimuli, several productive suffixes were selected ("*gile*", "*te*", "*dun*", "*le*", "*koi*", "*kari*", "*kor*", "*ti*", "*keta*", "*txo*", "*tsu*", "*keria*", "*lari*", "*zain*", "*ar*", "*kera*", "*tza*", "*tegi*", "*go*"), in order to increase the bias towards processing the constituent morphemes of the items (Bertram, Schreuder, & Baayen, 2000). Morphologically simple pseudowords were constructed aiming to minimise orthographic neighbourhood size and were thus the only condition in which stimuli had on average fewer orthographic neighbours. However, due to the high productivity of Basque morphemes and to the greater importance of controlling stem frequency, length and bigram variables over orthographic neighbourhood size, we could not minimise orthographic neighbourhood size to the same degree for the morphologically complex pseudowords. Lists were matched as much as possible on first sound variability. Finally, word frequency and stem frequency were matched across conditions. All stimuli and descriptive statistics on relevant variables are presented in Appendix C (page 187).

Procedure. Stimuli were centrally presented on the screen. In each trial, children were presented with a 500 ms fixation cross followed by the target item, which remained on the screen until response (see figure 5.1). Participants were instructed to read the item aloud as quickly and as accurately as possible. As soon as the child finished naming, the experimenter proceeded to the next trial by button press: this measure was recorded as the naming time. The experimenter was a research assistant trained on the techniques but blind to the purpose of the study, who had at no point been informed of the aims and hypotheses tested. Stimuli were presented in fixed order and blocked by condition in order to maximize effects, with the words presented before the pseudowords, morphologically complex items before morphologically simple items. Both accuracy and naming times for each trial and individual were analysed. Five practice trials were presented at the beginning of the task.

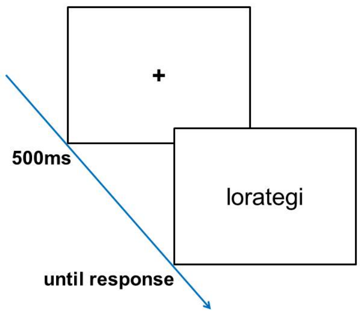


Figure 5.1: Naming paradigm

5.2.2.2 Visual Attention Span: Visual one-back task

In this study the five-consonant visual 1-back task (page 41) was used to measure visual attention span skills for children in both the 2nd and 4th grade[1]. Accuracy at each position and for absent trials was recorded, and was used to calculate a sensitivity index (d-prime) that was used in the analysis. Only participants who performed more than 60% of the trials were included in the analysis.

5.2.2.3 Control Tasks

These tasks were included in order to take into account other variables that could give rise to individual variability in reading in Basque.

Non-verbal intelligence. Non-verbal reasoning skills were assessed using the matrix reasoning subtest of the WISC battery (Fourth edition: Wechsler, 2003) that provides a measure of fluid reasoning. The individual scores were converted to scaled scores based on chronological age.

Vocabulary knowledge. This task was an adaptation of the definition subset of the WISC battery in Spanish and consisted in presenting the children with a Basque word and asking them to provide a definition of this word (in Basque). There were 18 words. Mean accuracy scores were calculated.

Phonemic awareness. Phoneme deletion abilities were measured with a task composed of 24 Basque-like bisyllabic pseudowords. Item presentation was randomized and there was a pause in the middle of the task. The pseudowords were presented over headphones while a central fixation cross was on the screen. Children were instructed to remove the first smallest sound they could identify, and produce the remaining item (e.g., /flope/->/lope/). Removing the first sound never resulted in a Basque or Spanish word. Response time was unlimited and, following a response, the experimenter proceeded to the next trial by button press. Two practice trials with feedback were administered. An individual index of average accuracy was calculated.

Single letter processing. An individual index of single, as opposed to multi-letter processing (measured in the visual one-back task) was calculated with the single letter identification task (page 42). The weighted sum of performance on the task was used to control for single letter processing skills.

[1] In this study we decided to use the same task for the 2nd and 4th grade readers in order to be able to analyze the VA span data of both grades together.

5.2.2.4 General Procedure

The tasks presented in this study were administered as part of a larger battery consisting of six 45-minute sessions that were performed with the teachers' permission during school hours and in a quiet room within the school. Tasks were carried out in four different orders and the computer-based tasks were administered using Presentation®.

5.2.3 Data Analyses

Overall performance on the control tasks and VA span was compared between grades using either Welch's t-test or Wilcoxon signed-rank tests. Naming accuracy and naming speed on accurate trials were analysed using logistic and linear mixed effects models respectively, with participants and items as crossed random effects (Baayen, 2008; Bates, Mächler, Bolker, & Walker, 2015; Jaeger, 2008). Mixed models were selected both in order to use similar methods for the analysis of naming accuracy and speed (high accuracy scores were more suited to a logistic mixed models analysis than to an ANOVA), and secondly due to the large individual variability in naming speed in early readers that can be better accounted for using mixed models. The large amount of trials available for each participant also made the use of mixed models possible (our previous studies involved fewer observations per participant and thus made fitting mixed models more difficult). P-values were computed based on the Satterthwaite approximation for linear mixed models (lmerTest package: Kuznetsova, Bruun Brockhoff, & Haubo Bojesen Christensen, 2014) and based on the normal approximation for logistic models. Hochberg corrections were applied for multiple-comparisons and post hoc comparisons were performed using the lsmeans package (Lenth, 2016).

5.3 Results

5.3.1 General comparisons

Comparisons between children of the 2nd and 4th grade demonstrated a significant age difference (t = -27.85, df = 55, p < .001), but no difference on age-standardised non-verbal intelligence (t = 0.91, df = 55, p = .37), single letter processing (U = 366.5, Z = -0.62, p = .54, r = .08), nor VA span skills (t = 0.09, df = 53, p = .93). Children in 4th grade also had greater vocabulary knowledge (t = -5.42, df = 53, p < .001) and tended to have better phonemic awareness skills (U = 304.5, Z = -1.68, p = .09, r = -.22) than children in 2nd grade (see table 5.1). An odd-even split was used to calculate split-half reliability of the phonemic awareness and vocabulary knowledge tasks. The correlations between individuals' scores on odd and even trials were adjusted using the Spearman-Brown prophecy formula to approximate the reliability of the tests overall. For the phonemic awareness task this yielded a coefficient of 0.87 for the 2nd grade and a coefficient of 0.85 for the 4th grade. For the vocabulary knowledge task this yielded a coefficient of 0.85 for the 2nd grade and a coefficient of 0.79 for the 4th grade.

Table 5.1: Descriptive statistics on age and performance on control tasks in both grades

	2nd grade N=27 (F=16)			**4th grade** N=30 (F=18)		
	Mean *(SD)*	Median	Range	Mean *(SD)*	Median	Range
Chronological Age						
(years)	7.81 (0.27)	7.83	7.33 – 8.25	9.93 (0.3)	10	9.5 – 10.5
Non-verbal intelligence						
(age-standardised)	12.56 (2.58)	13	7 – 17	11.9 (2.88)	12.5	7 – 16
Vocabulary Knowledge						
(average accuracy)	0.32 (0.08)	0.31	0.15 – 0.47	0.47 (0.11)	0.46	0.26 – 0.71
Phonemic Awareness						
(average accuracy)	0.84 (0.16)	0.92	0.5 – 1	0.9 (0.13)	0.92	0.58 – 1
Single Letter Processing						
(weighted score)	13.78 (1.06)	14	10.67 – 15	13.96 (0.89)	14.25	11.54 – 14.96
VA Span						
(average d-prime*)	1.14 (0.58)	1.12	0.15 – 2.38	1.13 (0.58)	0.99	0.25 – 2.33

Note. SD: standard deviation. * One 2nd grade subject was removed due to having performed the task incorrectly.

5.3.2 Naming Task

Naming speed scores were cleaned by applying upper and lower cut-offs of 500 and 10000 ms and removing values further than 3.5 standard deviations from the mean by subject and condition ($n_{removed}$=14, 0.17%[2]). Scores were subsequently log-transformed to approximate a normal distribution. For both the linear and logistic

[2]One morphologically complex pseudoword was also removed from the analysis because a simple transposition transformed it into a real word ("ordeztaku"-> "ordezkatu")

mixed models, categorical factors were coded as sum contrasts meaning that the intercept of the model represented the grand mean and the estimates corresponded to deviations from the grand mean for each level of the factor. Predicted scores based on the mixed models were produced using the effects package (Fox, 2003) in order to plot both predicted and original data.

5.3.2.1 Morphological effects in naming.

The categorical factors of lexicality, morphological complexity, grade, and their interactions were included in the models. In the accuracy analysis, log-transformed reaction times were also included as a continuous predictor (centred on 0), accounting for speed-accuracy trade-offs (Davidson & Martin, 2013). All linear models included random intercepts for subjects and items, as well as random slopes for subjects for morphological complexity and lexicality effects and their interaction. Convergence problems in logistic models led to the simplification of the random effects, including only random intercepts for subjects and items[3]. Descriptive statistics of the data are provided in table 5.2. The additional analysis of the differences between the two different types of morphologically complex pseudowords (stem + pseudosuffix, pseudostem + suffix) showed no effect of type of pseudoword or interaction with grade for either accuracy or naming speed (ps > .25) and is not presented. The results of our additional analyses on morphologically complex words (studying word and stem frequency effects) are briefly summarised in a separate section following our main analyses.

Naming accuracy. The analysis resulted in an effect of log-transformed reaction times (Intercept =3.59, β = -1.60, z = -9.89, p < .0001), an effect of lexicality (β = -2.30 x 10^{-1}, z = -3.31, p = .0009), an effect of morphological complexity (β = -2.73 x 10^{-1}, z = -4.03, p = .0001), and a grade by lexicality by morphological complexity interaction (β = -1.29 x 10^{-1}, z = -2.43, p = .015, figure 5.2).

Post hoc comparisons on the lexicality by morphological complexity interaction within each grade showed that an advantage in naming morphologically complex over morphologically simple items was present for words in the 2nd grade (β = 8.59 x 10^{-1}, z = 3.34, p = .0099), and for pseudowords in the 4th grade (β = 7.50 x 10^{-1},

[3]Convergence warnings persisted even for the simplified models but comparison to converging models with the same random effects structure but with an increased number of optimizer iterations (max 100000) resulted in the same patterns of significance so warnings were considered a false positive. High accuracy, particularly in word naming, could be one source of convergence problems and highlights lower reliability of the estimates.

Table 5.2: Descriptive statistics on performance in each condition of the naming task for both grades (original data)

Lexicality	Morphological Complexity	Measure		Grade 2nd N=26* (F=16)	Grade 4th N=30 (F=18)
Words					
	Complex	Speed	Mean *(SD)*	2245 (437)	1643 (315)
			Median	2272	1546
			Range	1442 - 3127	1132 - 2446
		Accuracy	Mean *(SD)*	0.97 (0.04)	0.98 (0.03)
			Median	0.98	0.99
			Range	0.85 - 1	0.88 - 1
	Simple	Speed	Mean *(SD)*	2189 (498)	1591 (359)
			Median	2145	1530
			Range	1293 - 3555	927 - 2421
		Accuracy	Mean *(SD)*	0.94 (0.08)	0.97 (0.04)
			Median	0.98	1
			Range	0.68 - 1	0.82 - 1
Pseudowords					
	Complex	Speed	Mean *(SD)*	2664 (465)	2096 (475)
			Median	2723	2002
			Range	1885 - 3822	1261 - 3325
		Accuracy	Mean *(SD)*	0.93 (0.06)	0.96 (0.07)
			Median	0.95	0.97
			Range	0.76 - 1	0.67 - 1
	Simple	Speed	Mean *(SD)*	2802 (603)	2130 (470)
			Median	2778	2123
			Range	1818 - 4283	1392 - 3322
		Accuracy	Mean *(SD)*	0.91 (0.07)	0.92 (0.08)
			Median	0.94	0.95
			Range	0.7 - 1	0.67- 1

Note. SD: standard deviation. * The participant who was removed from the VA span analysis was also removed from the naming task analyses.

z = 3.46, p = .006). Moreover, lexicality effects (the difference in word as compared to pseudoword naming accuracy) were marginal only for morphologically complex items in the 2nd grade (complex: β = 6.84 x 10^{-1}, z = 2.66, p = .07 ; simple: β = 9.81 x 10^{-2}, z = 0.46, p = .64), while in the 4th grade the opposite was true with significant lexicality effects only for morphologically simple items (complex: β = 3.07 x 10^{-1}, z = 1.13, p = .64 ; simple: β = 7.54 x 10^{-1} , z = 3.18, p = .015).

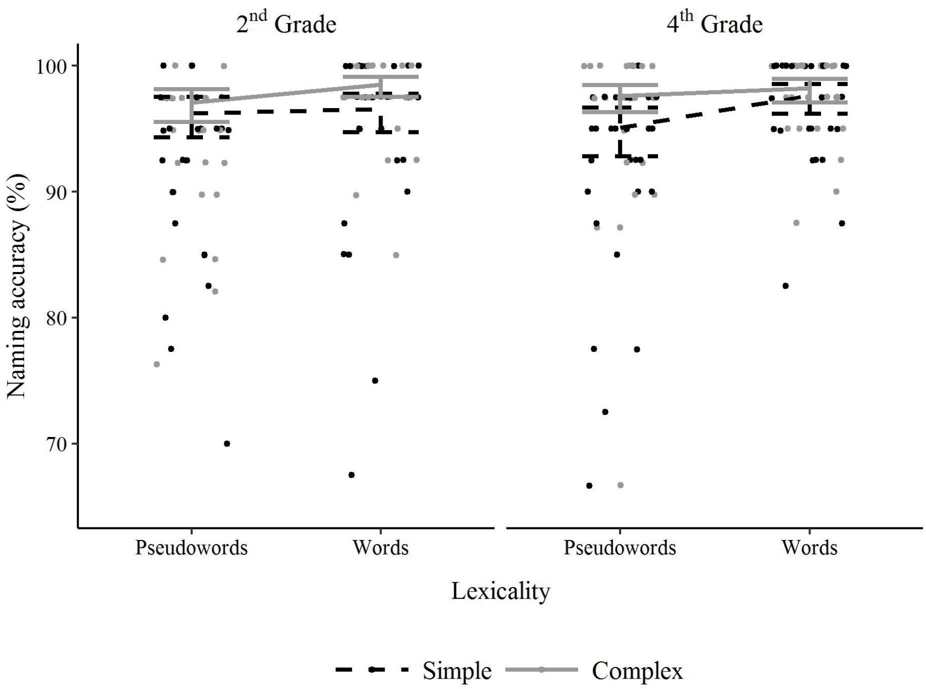


Figure 5.2: Grade by lexicality by morphological complexity interaction on naming accuracy. Lines represent model predictions for means by condition and upper and lower 95% confidence intervals. Points represent by subject and condition averaged original scores.

Naming times. The analysis resulted in significant effects of lexicality (Intercept= 7.61, β = 1.20 x 10^{-1}, t = 8.62, p < .0001) and grade (β = 1.46 x 10^{-1}, t = 5.71, p < .0001), indicating that children in both grades read words faster than pseudowords, and that children in 4th grade read overall faster than children in 2nd grade. There was also a marginal grade by lexicality interaction (β = -1.42 x 10^{-2}, t = -1.82, p = .07), suggesting a trend for larger lexicality effects in the 4th grade.

Additional analysis of morphologically complex words. Only naming speed was analysed since naming accuracy was very high in both morphologically complex and simple words. For completeness we firstly tested all words (complex and simple) with morphological complexity, word frequency, grade and their interactions as categorical factors coded as sum contrasts. Random intercepts for subjects and items were also included, as well as random slopes for subjects for morphological complexity, word frequency and their interaction. The analysis resulted in significant effects of word frequency (Intercept= 7.49, β = 7.83 x 10^{-2}, t = 4.93, $p < .0001$) and grade (β = 1.60 x 10^{-1}, t = 6.00, $p < .0001$). No other effects or interactions were significant ($ps > .10$).

We then focused on morphologically complex words only. The categorical factors grade, word frequency, stem frequency and their interaction were included as fixed factors in the mixed effects model. Random intercepts for subjects and items were also included, as well as random slopes for subjects for word frequency, stem frequency and their interaction. It should be noted that low stem frequency words could not be matched across the high and low whole word frequency conditions[4]. The analysis resulted in significant effects of word frequency (Intercept= 7.50, β = 7.61 x 10^{-2}, t = 3.14, p = .003), stem frequency (β = 6.59 x 10^{-2}, t = 2.74, p = .009) and grade (β = 1.58 x 10^{-1}, t = 6.43, $p < .0001$). The effect of word frequency indicated that high frequency words were named faster than low frequency words. The effect of stem frequency showed that words with high frequency stems were named faster than words with low frequency stems. There was no interaction between these factors ($ps > .23$).

5.3.2.2 Contribution of VA span to naming and its modulation by lexical and morphological factors.

Separate analyses were conducted for each grade, including the categorical lexicality and morphological complexity factors, as well as the continuous VA span variable, together with their interactions. Chronological age, non-verbal intelligence, single letter processing, vocabulary knowledge and phonemic awareness skills were included as control variables. All the continuous variables were mean-centred, thus the intercept corresponded to the grand mean for each factor when continuous variables were equal to their mean. The same random effects as in the previous analyses were included. Because we had clear a priori hypotheses (see the introduction), we exclusively focused on the effects involving the VA span.

Naming accuracy. The analysis of the accuracy data from the children in 2nd

[4] Low stem frequency words of low whole word frequency had stems of lower average stem frequency than the low stem frequency words of words with high whole word frequency.

grade demonstrated a main effect of VA span (Intercept=3.34, β = 7.69 x 10^{-1}, z = 2.45, p = .014) indicating that a larger VA span was related to more accurate naming. The analysis of the accuracy data from the children in 4^{th} grade showed no effects or interactions involving VA span skills (Intercept = 3.82, ps > .13).

Naming times. The analysis of the naming speed data from the children in 2^{nd} grade showed no effects or interactions involving VA span skills (Intercept = 7.75, ps > .26). The analysis of the naming speed data from the children in 4^{th} grade demonstrated a significant interaction including VA span skills: the lexicality by morphological complexity by VA span interaction (Intercept = 7.46, β = 2.46 x 10^{-2}, t = 2.07, p = .048).

To interpret the interaction post hoc comparisons were used to test the significance of lexicality effects for morphologically simple and complex items at different values of VA span skills (ranging from the lowest scaled value of -0.88 to the highest value of 1.19). The tests showed that all lexicality effects (the comparison of pseudoword and word naming speed) were significant (ps < .002). However, for morphologically complex items lexicality effects were similar across different values of VA span skills (e.g., $t_{(VA\ span=-0.88)}$ = 4.04, $t_{(VA\ span=-0.48)}$ = 4.97, $t_{(VA\ span=-0.08)}$ = 5.57, $t_{(VA\ span=0.32)}$ = 5.15, $t_{(VA\ span=0.72)}$ = 4.16, $t_{(VA\ span=1.12)}$ = 3.26) , while for morphologically simple items a larger VA span was related to larger lexicality effects (e.g., $t_{(VA\ span=-0.88)}$ = 3.96, $t_{(VA\ span=-0.48)}$ = 5.60, $t_{(VA\ span=-0.08)}$ = 7.10, $t_{(VA\ span=0.32)}$ = 7.60, $t_{(VA\ span=0.72)}$ = 7.13, $t_{(VA\ span=1.12)}$ = 6.34, see figure 5.3).

Thus, for morphologically simple items only, VA span skills modulated lexicality effects: a larger VA span was linked to larger lexicality effects for simple but not complex items. This demonstrated that a larger VA span was significantly related to larger differences between coarse (word) and fine (pseudoword) grain processing speed for morphologically simple items. The absence of a main effect of VA span skills despite the presence of the triple interaction suggested that the VA span was significantly related to the difference in naming speed for morphologically simple words and pseudowords but not to absolute speed of naming speed in any of these conditions.

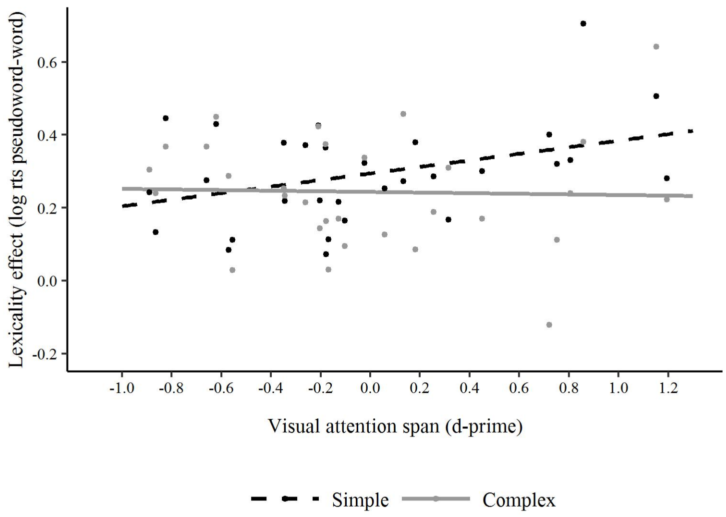


Figure 5.3: Influence of VA span skills on lexicality effects on naming times in 4th grade. Points represent by subject lexicality effects (by subject averaged pseudoword - word log naming times), lines reflect lexicality effects as calculated based on model predictions on naming times averaged by condition and VA span scores (ranging from -1 to 1.2 with a step of 0.01). A positive lexicality effect indicates words were named more rapidly than pseudowords.

5.4 Discussion

The present study aimed to test whether young readers of Basque would: a) show a naming benefit when naming words and pseudowords including sub-lexical morphemes (indicating that morphemes act as large, salient orthographic grains), and b) demonstrate differences in the influence of VA span skills on naming depending on the presence of sub-lexical morphemes in the stimuli (indicating that the presence of morphemes modulates the orthographic grain size used in reading). The main results on these two points could be summarised as follow: a) a significant morphological benefit was observed on the naming accuracy of words in early readers, and of pseudowords in advanced readers, b) for children in 2nd grade, a larger VA span was related to more accurate naming regardless of morphological structure, whereas in 4th grade a larger VA span was related to lexicality effects (differences in naming performance on words as compared to pseudowords) for the morphologically simple items. The following sections discuss these results in light of previous studies and in relation to orthographic grain size.

5.4.1 Morphological benefit in naming.

The morphological benefits observed on naming accuracy indicated that readers of Basque were sensitive to the morphological structure of the stimuli (see also Acha et al., 2010, for similar results with inflectional morphology). Studies on other shallow alphabetic orthographies have shown a morphological benefit in early readers for both words and pseudowords and in advanced readers for unfamiliar stimuli only (Angelelli et al., 2014; Burani et al., 2008, 2002; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013; Traficante et al., 2011). Accordingly, we found a morphological benefit in early readers for words (but not pseudowords), and in advanced readers for pseudowords only.

We argue that the presence of a morphological benefit in pseudoword naming in 4th but not 2nd grade children is related to the morphological composition of the complex pseudowords, which were made up of a single real morpheme (stem or suffix) and a pseudomorpheme, and reflects 4th grade readers' increased ability to process larger orthographic grains even during fine grain phonological decoding. More specifically, at the early stages of reading acquisition, fine grain processing mainly relies on grapheme to phoneme mapping rather than processing larger orthographic grains such as morphemes (Ehri, 2005; Frith, 1985; Share & Stanovich, 1995). Thus, it may have been more difficult for children in the 2nd grade to identify morphemes embedded in the pseudowords. Certainly, constructing morphologically complex pseudowords using two real morphemes (as was the case in previous studies: e.g., Burani et al., 2002) could increase the possibility of observing a benefit in early readers. This has been shown in a study in which pseudowords with a real stem and real suffix (in a non-existing combination) were read more accurately and faster than pseudowords with a pseudo stem and a real suffix, that were in turn read more accurately than pseudowords with a pseudo stem and a pseudo suffix (Colé et al., 2012). Importantly, although the benefit was clearer in the pseudowords with a real stem and a real suffix, a benefit was also observed in the pseudo stem and real suffix condition. Similarly Traficante et al. (2011) showed that naming accuracy was higher for pseudowords including either a real root or a real suffix, although onset of pronunciation was earlier only for those including a real root. The results of both these studies (Colé et al., 2012; Traficante et al., 2011) suggest that any regularity that has been internalized (either root or suffix) can exert facilitation on pseudoword reading, because of early activation of the root. Probably because of its earlier position in the word, the root has a special impact on naming onset. In the present study, whole word reading times were examined in order to capture any possible facilitation derived from any morpheme, regardless of whether it was positioned and thus identified earlier or later within the pseudoword. This could also explain the absence of any differences between the two types of pseudowords that composed the morphologically complex pseudoword condition (stem + pseudosuffix, pseudostem + suffix). Alternatively, it could be the case that whole word reading times are not a sensitive enough measure to study these differences, since they may also reflect additional sources of variability such as articulation speed. However, a previous study reported both lexicality and word frequency effects using this measure, suggesting it is a sensitive measure of such effects (Lallier et al., 2016).

With respect to word naming, the presence of a morphological benefit in accuracy for children in the 2nd but not the 4th grade suggests that whereas the presence of morphemes no longer affected word naming for skilled readers who probably identified most words as a whole (Angelelli et al., 2014; Marcolini et al., 2011), it may have boosted coarse grain processing in early readers who are still developing grapheme-to-phoneme reading skills. This may have resulted from the availability of the larger sub-lexical orthographic grains (morphemes), whose identification (particularly that of the stem) could boost the activation of the whole word (Beyersmann, Grainger, Casalis, & Ziegler, 2015; Hasenäcker, Beyersmann, & Schroeder, 2016). We further investigated this interpretation by comparing the proportion of lexicalisation errors compared to other types of errors in both age groups[5]. A higher proportion of lexicalisation errors is suggested to reflect greater reliance on coarse grain processing (N. C. Ellis et al., 2004). Although children in the two grades had similar odds of making lexicalisation errors overall (p = .64), children in the 2nd grade had significantly higher odds of making lexicalisation errors when naming morphologically complex as compared to simple words (5.5 times higher odds, 95% CI [1.31, 27.62], p = .04), while this was not the case for children in the 4th grade (p = .91). This supports the interpretation that coarse grain processing was boosted by the presence of morphemes for early readers when reading real lexical items, but not when reading pseudowords.

Our restrictive stimulus selection may have also limited the effects of morphological complexity in word naming speed. Note that previous studies have demonstrated that effects of stem frequency are observed in low frequency morphologically complex words (Deacon et al., 2011; also see Deacon & Francis, 2017). We included both high and low frequency morphologically complex words that in turn included both high and low frequency stems. However, our additional analysis of these factors[6] showed no interaction between these factors or between

[5] Simple comparisons between the proportions of lexicalisations were performed using Fisher's exact test and applying Hochberg corrections for multiple comparisons.

[6] This refers to the analysis of naming speed measures. Naming accuracy could not be analysed for

these factors and the other variables of interest. All children showed frequency effects in all word conditions suggesting reading time was generally driven by whole word frequencies despite morphological facilitation in accuracy. It could be the case that the inclusion of high frequency morphologically complex words may have decreased the bias towards processing their morphological constituents and even more so in the case of items with low frequency stems, leading to morphological effects in accuracy but not in reading times. The absence of an interaction between stem and whole word frequency (also reported in previous adult studies Baayen, Wurm, & Aycock, 2007) could also be an effect of either the blocked design of the experiment, or of the fact that stem frequency was lower in the low stem frequency words of low whole word frequency than in those of high whole word frequency.

Another limitation of our design that may have influenced our results was the use of fixed trial order for the presentation of our stimuli. Nevertheless, if trial order had a large influence on performance (particularly naming speed) the presentation of the complex stimuli before the simple stimuli should have increased the chance of seeing a morphological benefit. This was not the case.

Nonetheless, overall, this set of results suggests that sublexical units become accessible earlier than whole word units along the course of reading development, and may therefore serve as an intermediate grain (Burani et al., 2002; Hasenäcker et al., 2017) that facilitates the build-up of efficient and automatic lexical reading. If morphemes indeed act as a larger grain in reading, particularly at the level of orthographic processing (i.e., a larger orthographic grain), their influence could also be reflected by the role of VA span skills in reading. The relevant results regarding this hypothesis will be discussed in the following section.

5.4.2 Impact of morphology on the VA span-naming relationship.

The second aim of this study was to investigate whether the role of the VA span in reading was modulated by the presence of sub-lexical morphemes in orthographic strings, indicating the role of morphemes in modulating the orthographic grain size used in reading. Based on the results, better VA span skills related to: a) higher naming accuracy in 2nd grade children, b) larger lexicality effects in naming speed on morphologically simple items in 4th grade children (i.e., larger differences between word and pseudoword naming speed).

words only due to ceiling effects.

Regarding results in the 2nd grade children, we suggest that for early readers VA span skills support higher naming accuracy when the quality of lexical orthographic representations is still poor, in line with the suggestion that the VA span supports the construction of lexical orthographic representations (Bosse et al., 2013) and the overall processing of larger orthographic grains. However, this interpretation may be limited by the ceiling effects on naming accuracy which are characteristic of reading in shallow orthographies. In fact, after the first years of reading instruction in these orthographies, reading speed is the most sensitive measure of reading (Landerl & Wimmer, 2008; Seymour et al., 2003).

With regards to naming times, results showed that VA span skills influenced lexicality effects for advanced readers. More specifically, better VA span skills were significantly related to larger lexicality effects on the naming speed of morphologically simple items. This could be interpreted as better VA span skills being linked to larger differences between coarse (word) and fine-grain (pseudoword) processing speed and thus greater reliance on, or efficiency of, coarse grain processing (Frost et al., 1987; Lallier & Carreiras, 2018). Therefore, children in 4th grade with reduced VA spans exhibited the smallest lexicality effects on naming speed, indicating similar rate for reading lexical and sub-lexical orthographic grains, probably reflecting the use of similar fine grain sequential parsing strategies for the two types of items. In contrast, children with the largest VA spans demonstrated the greatest lexicality effects, likely to reflect an efficient use of the coarse grain route for these morphologically simple items. In addition, VA span skills did not influence lexicality effects for morphologically complex items, indicating that the presence of sub-lexical morphemes cancelled the contribution of VA span skills to naming speed differences between coarse and fine grain processing.

There are two alternative interpretations regarding why the presence of sub-lexical morphemes would eliminate the link between better VA span skills and larger lexicality effects, and how this could be interpreted in relation to orthographic grain size. First, the presence of sub-lexical morphemes could have boosted word naming (coarse grain processing) efficiency and thus lexicality effects in children with lower VA span skills. Indeed, the presence of morphemes in words might guide lexical orthographic parsing by breaking the word down into smaller and more accessible orthographic grains. The morphological status of these grains leads to more top down activation and also boosts whole-word processing. This interpretation would suggest that the presence of sub-lexical morphemes should increase the size of lexicality effects in children with worse VA span skills making them similar to those of children with better VA span skills. Nevertheless, a closer look at the data indicated that this was not the case; children with worse VA span skills showed similar lexicality effects for both complex and simple items while the interaction arose because children with better VA span skills tended to have larger lexicality effects for simple than complex items. This points towards the alternative interpretation: better VA span skills boosted coarse grain processing in the absence of sub-lexical morphemes. The presence of sub-lexical morphemes eliminated this advantage. This could reflect a “detrimental” effect of the presence of sub-lexical morphemes on the efficiency of coarse grain processing when children have the attentional resources to efficiently process both the whole word and its morphological constituents. The salience of the morpheme as a sub-lexical orthographic grain could interfere with the processing of the whole word and thus with the activation of the lexical orthographic representation. This interpretation is in line with studies indicating that drawing attention to sub-lexical morphemes may inhibit performance for skilled readers (Angelelli et al., 2014; Häikiö et al., 2011). This inhibitory effect depends on the length and frequency of the first constituent, and has been attributed to the cost of processing the root before processing the whole word while reading (Bertram & Hyönä, 2003). The fact that adults show longer gaze durations -interpreted as indicating additional processing cost- for morphologically complex than for simple words in other morphologically rich agglutinative languages provides support for this interpretation (Hyönä, Yan, & Vainio, 2018; Yan et al., 2014).

In line with this interpretation, a potential variable that could explain the link between VA span skills and lexicality effects in the 4th grade was orthographic neighbourhood size. Concretely, this factor might be the reason for the presence of larger lexicality effects in morphologically simple items in the 4th grade, particularly for children with a larger VA span. As noted in the methods section, morphologically simple pseudowords were the only set of stimuli that had fewer orthographic neighbours. This could explain why children with a large VA span showed larger lexicality effects in simple items, for which the difference in processing words and pseudowords was coupled with a greater difference in orthographic neighbourhood size. If, as stated in the introduction, a larger orthographic neighbourhood biases towards coarse grain processing and thus towards greater reliance on VA span skills (Ans et al., 1998) this could also explain the absence of a modulation of lexicality effects by VA span skills in the morphologically complex stimuli. More specifically, VA span skills may have been similarly involved in processing morphologically complex words and morphologically complex pseudowords if both types of item had similar numbers of orthographic neighbours and thus biased readers towards lexical, coarse grain processing. We consider this unlikely given our blocked design in which the readers are more likely to notice they are reading a list of pseudowords (even if they are morphologically complex). When reading a list of pseudowords it is more appropriate to consider that by default the VA span will focus on sub-lexical processing (Ans et al., 1998), and thus be less susceptible to orthographic neighbourhood effects. Still, we decided to test whether adding the number of orthographic neighbours as a control variable in the fixed effects of all our models would change the observed effects. The pattern of significance remained the same suggesting that differences in orthographic neighbourhood size did not drive our results.

Our findings also support a relation between VA span skills and word naming in Basque. Nevertheless, the previously reported correlation between better VA span skills and faster word/pseudoword naming in other alphabetic orthographies (e.g., Germano et al., 2014; van den Boer et al., 2013, 2014, 2015), and between better VA span skills and faster text reading in Basque skilled adult readers (see chapter 4) was absent. Two language-related factors may decrease the role of VA span skills in Basque: the shallow orthography and the rich agglutinative morphology. While the VA span - reading fluency correlation has been reported in other shallow orthographies (Spanish: Lallier et al., 2014; Onochie-Quintanilla et al., 2017, Dutch: van den Boer et al., 2013, 2014, 2015), there is also evidence that it may be weaker than in deeper orthographies. For example, Onochie-Quintanilla et al. (2017) found that VA span significantly predicted reading fluency only for low frequency, long words, while Awadh et al. (2016) reported that VA span skills correlated with adult reading fluency in readers of French (a deeper orthography), but not Spanish. In the case of Basque, its rich and productive derivational morphology is not the only factor that may affect the VA span contribution to reading. In fact, the agglutinative nature of this language generates polymorphemic words composed of easily identifiable high frequency morphemes such as articles, postpositions, and inflections. As a result, reading in Basque may require higher sensitivity to morphological and syntactic structures at the word level and thus involve different visual attentional strategies. Cross-linguistic studies on similarly shallow orthographies that differ in relation to their morphology, such as Spanish and Basque, could shed light on this issue.

Chapter Summary

Our results support that both early and advanced readers of Basque are sensitive to the presence of sub-lexical morphemes, primarily when coarse grain processing fails and morphemes are the largest salient grain available. Moreover, the role of VA span skills in naming is modulated by the presence of sub-lexical morphemes in advanced but not early readers. This could suggest that the influence of morphemes at the orthographic level develops later on in reading development (Grainger & Beyersmann, 2017). These results are in line with the results of chapter 3, which highlighted differences in the size of the orthographic grain used in reading (modulated by orthographic depth) also evolved after the first two years of reading instruction and thus in more advanced readers. Further research on the influence of visuo-attentional demands in reading development should explore both the influence of orthographic consistency and morphological complexity in order to understand the obstacles faced by poor readers of different languages (also see: Diamanti et al., 2018).

Chapter 6

The influence of stems and suffixes on the deployment of visual attention across orthographic stimuli

6.1 Introduction

The previous chapter provided evidence that typically developing readers of Basque are sensitive to morphemes in reading and that, particularly in more advanced readers, the presence of morphemes in orthographic stimuli (either words or pseudowords) can modulate the orthographic grain size in reading and subsequently the role of VA span skills. The absence of an influence of VA span skills in reading in the presence of morphemes raises further questions regarding how morphemes influence the deployment of visual attention across the orthographic string, and whether the influence of stems and suffixes could be different. The present study aims to shed some light on this question, from the perspective of orthographic processing and VA span skills.

How stems and suffixes are processed in written words and pseudowords has been addressed in different languages (Bertram et al., 2000; Burani et al., 2002; Diependaele, Morris, Serota, Bertrand, & Grainger, 2013; Duñabeitia et al., 2007; Frost, Kugler, Deutsch, & Forster, 2005; Grainger, Colé, & Segui, 1991; Laudanna, Badecker, & Caramazza, 1992; Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, & New, 2004; Taft & Forster, 1976; Taft & Nguyen-Hoan, 2010). Because morphemes are recurrent orthographic regularities, stems and suffixes might be easily internalized as reading experience and skills develop, and activated to boost lexical access particularly in transparent (German: Hasenäcker et al., 2016) and semi-transparent orthographies (French: Quémart, Casalis, & Colé, 2011). Thus, the early internalization of stems and suffixes could influence letter coding strategies and unfamiliar and familiar word reading from early stages of orthographic processing (for a review on morphological processing in skilled reading see: Amenta & Crepaldi, 2012). In turn this could also affect the deployment of visual attention across letter strings, as indicated by the results of chapter 5.

As highlighted throughout the thesis, the visual attention (VA) span is a measure of the ability to deploy visual attention across multiple elements, including letter strings and is a strong candidate to measure orthographic grain size. As mentioned in all of the previous chapters the VA span is defined as the number of individual elements that can be processed (independently) in a multi-element array in a single fixation (Bosse et al., 2007). The VA span is linked both to orthographic processing (Bosse et al., 2013) and reading development across alphabetic orthographies (e.g., Bosse & Valdois, 2009; Germano et al., 2014; van den Boer et al., 2015). Despite the existent literature supporting the facilitative role of stems and suffixes in word identification, no work has examined to what extent these internalized structures can influence the reader's visual attentional strategy for orthographic coding. The aim of this study is to explore this issue in beginning readers of Basque, a transparent and morphologically rich orthography.

One way to determine whether the morphological structure of a word affects the deployment of visual attention across it is to manipulate the presence of morphemes in orthographic items, following the rationale of the studies designed to explore this issue in lexical access. Some studies on developing readers (Casalis et al., 2015; Quémart et al., 2012; Traficante et al., 2011) orthogonally manipulated the presence of stems and suffixes in pseudowords in order to explore the role of each type of "regularity" on pseudoword identification. These studies included items with: a) neither a stem nor a suffix (-stem -suffix), b) a stem and a pseudo-suffix (+stem -suffix), c) a pseudo-stem and a suffix (-stem +suffix), and d) both a stem and a suffix in a non-existing combination (+stem +suffix). Studies showed a benefit in naming accuracy for pseudowords including either stems or suffixes (Traficante et al., 2011). In lexical decision, studies showed a disadvantage for pseudowords including both stems and suffixes – in such paradigms, pseudowords are indeed more likely to be mistaken for words (Burani et al., 2002; Casalis et al., 2015; Quémart et al., 2012). For speed, there was a benefit in naming only when stems were present in pseudowords, and a disadvantage in lexical decision either when pseudowords included stems and/or suffixes (Quémart et al., 2012), or when pseudowords included suffixes (Casalis et al., 2015). Overall this indicates that not only suffixes but also stems influence processing, possibly with a more salient role for stems in naming and suffixes in lexical decision.

Nevertheless, the aforementioned pattern could also be due either to the difficulty in internalizing suffixes (opaque languages) or to the fact that they have not been encountered a sufficient number of times as to be internalized (beginning readers). In fact, recent studies have shown that children learning to read in highly transparent languages are able to use internalized regularities very early in reading development (Lázaro et al., 2017), and are sensitive both to stems and suffixes as highlighted by facilitation effects on tasks tapping lexical access (Hasenäcker et al., 2016). This effect might be even more evident in children exposed to morphologically rich languages such as Basque (although see chapter 5), a highly transparent and morphologically complex orthography. The early use of such regularities might boost the ability to use larger orthographic grains during reading, also increasing the bias towards whole-word processing. As a result, this may impact how the visual attention resources of developing readers are distributed across orthographic strings. This issue still remains unexplored.

The present study aimed to determine how morphological information present in pseudowords affects the deployment of Basque children's visual attention by manipulating the presence of a real stem or a real suffix within the pseudowords. To that end, we used a visual one-back task a paradigm similar to that used in the studies with developing readers in chapters 3 and 5 to measure the deployment of VA span skills across letter strings (also used in: Lallier et al., 2016). As presented in the methodological considerations chapter (page 37) the task consists of a brief presentation of a string of letters (for approximately 200 ms, allowing a unique fixation on the string), followed by a target letter. The participant has to report whether or not the target letter was present in the previously presented letter string. In the present study, the string of letters was not a consonant string but corresponded either to a pseudoword with a morphologically simple structure (no morpheme) or with a morphologically complex structure (including a real stem with a pseudo-suffix, or a pseudo-stem with a real suffix; +stem-suffix, -stem+suffix[1]). As discussed previously, this task taps into early perceptual and attentional processes that could influence orthographic coding strategies and lexical access.

As presented previously, in the present study the string of letters corresponded either to a pseudoword with a morphologically simple structure (no morpheme)

[1]A pseudoword condition with a stem and suffix (+stem+suffix) was excluded because few pseudowords of this type could be created while also controlling for letter repetition (see Methods).

or with a morphologically complex structure. We firstly expected a left-to-right decrease in target letter detection performance. Indeed, a previous study using this paradigm with words and nonwords reported a left-to-right decrease in letter identification performance only for nonwords (Lallier, Carreiras, et al., 2013). Secondly, we expected that easier processing of morphemic orthographic grains could increase the availability of visual attentional resources to process the remainder of the pseudoword (the non-real constituent), boosting target letter detection across the whole letter string for morphologically complex as opposed to morphologically simple stimuli. Thirdly, we predicted that the detection of target letters presented within real stems or real suffixes (identified as recurrent regularities) would be facilitated as they would be part of orthographic grains consolidated in memory and, thus, accessed automatically. We considered this would lead to differences in letter detection performance depending on the type of real morpheme (stem or suffix) included in the pseudoword. Lastly, we expected to find significant correlations between performance on the classic VA span one-back task previously performed by these children (see chapter 5), and our morphological one-back task, especially in the absence of morphemes, since the presence of morphemes could facilitate processing and reduce the visual processing load (as is the case for words: Lallier, Carreiras, et al., 2013) and thus interfere with VA span demands (also observed in the previous chapter).

6.2 Methods

6.2.1 Participants

The 4^{th} grade children who participated in the study presented in chapter 5 also performed the morphological visual one-back task presented here. As mentioned previously, these children attended primary school education in the Spanish-Basque region of the Basque Country (Spain) and were native speakers of Basque with Spanish as a second language. This age was chosen to assure that they had enough reading experience as to be prone to facilitative effects of the presence of morphemes (Lázaro et al., 2017), particularly at the orthographic level (see our previous results and Grainger & Beyersmann, 2017). Language background information was acquired through a questionnaire completed by the child's (parent or) legal guardian. Two children were removed from the analysis, leaving a total of 30 children. Teaching was in Basque with only courses on English and Spanish language taught in the respective languages. The legal tutor of each child was informed about the techniques, duration and goals of the study and provided written consent for the child's participation. The project was approved by the ethical committee of the Basque Center on Cognition, Brain and Language.

6.2.2 Morphological visual one-back task

Stimuli consisted of 216 seven-letter pseudowords without letter repetition in a single string (see Appendix D, page 193 for a full list of the items). Of the 216 pseudowords, 144 were used in trials in which the target letter was present in the pseudoword (target-present trials), and 72 were used in trials in which the target was absent from the pseudoword (target-absent trials). Half of these trials included morphologically simple pseudowords (-stem-sufffix) and the rest included morphologically complex pseudowords.

Morphologically complex pseudowords were constructed including a stem or a suffix (+stem-suffix/-stem+suffix). Target letters were limited to three vowels ("*a*", "*i*", "*o*") and their presentation was restricted to one of three target positions, initial (first), central-fixation (fourth), and final (seventh). These restrictions were implemented to closely control the number of times the target letters appeared in each of the possible target positions across all trials (not only those in which they were presented as targets). Moreover, due to debate as to whether vowels are processed differently than consonants (e.g., Carreiras, Gillon-Dowens, Vergara, & Perea, 2009; Duñabeitia & Carreiras, 2011; Perea, Marcet, & Acha, 2017) conditions (morphologically simple/complex items in target-present/absent trials) were matched on the mean number of overall ($ps > .54$) and target ($ps > .27$) vowels per pseudoword. Pseudowords across conditions were also matched on mean log bigram token frequency (morphologically complex pseudowords: Mean_{btf} =1.56, morphologically simple pseudowords: Mean_{btf} =1.57) as calculated based on the E-Hitz database (Perea et al., 2006). Frequencies of stems and suffixes were also matched across conditions (M_{stemFreq}=118; $M_{\text{suffixFreq}}$=139 per million) according to the EHME database (Acha et al., 2014).

Six stems ("*aho*", "*ate*", "*igo*", "*oin*", "*ile*", "*ohe*"), and suffixes ("*koi*", "*txo*", "*era*", "*tza*", "*aro*", "*gai*") were each used nine times to construct the morphologically complex pseudowords of both the target-present and absent trials[2]. Therefore target letters appearing in the fourth position of a morphologically complex pseudoword were always adjacent to a morpheme, while target letters in the first and seventh position were within the morpheme or the pseudomorpheme. Target letters were presented as targets an equal number of times in each position within the

[2]Repetition was used for both stems and suffixes because it is usually the case that only suffixes are used repeatedly within stimuli.

target-present and absent trials. The number of times each letter appeared in each letter position in each condition was also calculated in order to avoid clear repetition of specific patterns in certain conditions (e.g., infrequent letters appearing consistently in morphologically complex but not simple pseudowords).

The construction of the stimuli was aimed to perform two comparisons. First of all, to compare letter detection across the three target positions between morphologically simple and morphologically complex pseudowords in order to test whether the presence of a real morpheme would provide an overall advantage in performance. Second of all, to compare letter detection across the three target positions in complex pseudowords with a real stem (+stem-suffix) as compared to those with are real suffix (-stem+suffix), in order to test whether the type of familiar morpheme would have a different effect on performance.

Procedure: Stimuli were presented on a white screen in black upper-case Arial font and children were seated 100 cm away from the screen. Stimulus width varied between 5.2° and 5.5° of visual angle and the centre-to-centre distance between each adjacent letter was 1.2° to minimize lateral masking effects. In each trial, a central fixation point was displayed for 1000 ms, followed by the centred letter string for 200 ms. The consonant string was followed by a white screen lasting 100 ms and a single letter (target) appearing centrally (in relation to the horizontal axis) and below the median horizontal line. Target letters were presented in red with a bold-italic font to reduce visual similarity with the preceding letter strings. Children were instructed to respond as fast as possible by pressing the “Alt Gr” key (on the right) when the target letter was present in the previously presented consonant string, and the “Alt” key (on the left) when it was absent. The target disappeared after the child’s response, and a screen with a question mark in the centre was presented until the experimenter pressed the left mouse button to initiate the next trial. Responses were recorded between 150 and 3000 ms after the target appeared. Trial order was randomized. The experimenter pressed the button to proceed to the next trial (figure 6.1). At the beginning of the task six practice trials were provided with feedback. Accuracy was recorded for each trial and was used to calculate an individual sensitivity (average d-prime sensitivity index) separately for each of the analysed conditions.

6.2.3 Visual Attention Span: Visual one-back task

As mentioned in the previous chapter, in this study the five-consonant visual one-back task (page 41) was used to measure visual attention span skills. Accuracy at each position and for absent trials was recorded, and was used to calculate a

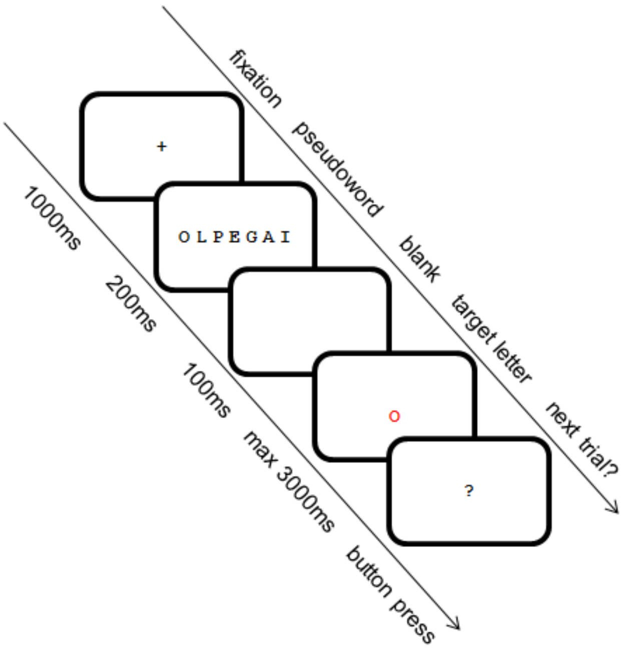


Figure 6.1: Morphological visual one-back paradigm

sensitivity index (d-prime) that was used in the analysis. Only participants who performed more than 60% of the trials were included in the analysis.

6.2.4 Control Tasks and General Procedure

The non-verbal intelligence and single letter processing control tasks presented in the previous chapter were used as control measures in the present study (page 93). The general procedure was the same as that described in the previous chapter (page 94).

6.2.5 Data Analyses

In a first Type II ANOVA including the performance across all items in the task, d-prime sensitivity on the morphological visual one-back task was analysed with Target Position (first, fourth, or seventh) and Morphological Complexity (simple vs. complex pseudowords) as within-subject factors. This first ANOVA aimed to test the effect of Target position but also whether there would be an overall benefit in letter detection performance due to the presence of a real morpheme (either a stem or a suffix) in the complex pseudowords. Then a second Type II ANOVA including only the performance on morphologically complex pseudowords was conducted on d-prime values, with Target Position (first, fourth, or seventh) and Morphological Structure (+stem-suffix, -stem+suffix) as within subject factors. This second ANOVA aimed to further test whether the presence of a familiar stem would have a different effect on letter detection performance than the presence of a familiar suffix. Greenhouse-Geisser corrections were used when assumptions of sphericity were violated. Post-hoc comparisons were performed using least-square means (lsmeans package: Lenth, 2016) that compute degrees of freedom based on the Satterthwaite approximation. Significance of multiple comparisons was adjusted using Hochberg corrections. ANOVAs and post hoc tests were performed using the ULL R Toolbox (Hernández-Cabrera, 2012).

Finally a linear mixed regression model was used to define the degree to which average VA span sensitivity was related to performance on the morphological visual one-back task. Average d-prime sensitivity across all target positions for each of the three types of pseudoword (-stem-suffix, +stem-suffix, -stem+suffix) was used as the outcome variable[3]. Average d-prime sensitivity on the VA span task was used as a continuous predictor of interest and was allowed to interact with the categorical factor type of pseudoword. Age, age-standardised non-verbal intelligence and single letter processing skills were included as control variables. VA span skills and the control variables were mean-centred and by-subject intercepts were included in the random effects (random by subject slopes for type of pseudoword could not be included since there were not enough observations for them to be computed and this led to convergence issues).

6.3 Results

Descriptive statistics on children's age, standardised non-verbal intelligence, single letter processing and VA span skills are presented in table 6.1.

[3]It should be noted that sensitivity on simple pseudowords reflects the average across twice as many datapoints as in the other conditions.

Table 6.1: Descriptive statistics on control variables for the 30 4th grade children

	Mean *(SD)*	Median	Range
Chronological Age			
(years)	9.93 (0.3)	10	9.5 – 10.5
Non-verbal intelligence			
(age-standardised)	11.9 (2.88)	12.5	7 – 16
Single Letter Processing			
(weighted score)	13.96 (0.89)	14.25	11.54 – 14.96
VA Span			
(average d-prime*)	1.13 (0.58)	0.99	0.25 – 2.33

Note. SD: standard deviation.

6.3.1 Morphological visual one-back task

D-prime sensitivity scores on each target position and for each type of pseudoword[4] are presented in table 6.2 (accuracy scores by condition are presented in D.2 of Appendix D). The original d-prime scores were analysed since they were normally distributed.

The Type II ANOVA on d-prime values across all stimuli (i.e., both morphologically complex and simple pseudowords) showed an effect of Target Position ($F(2,58) = 8.66, p = .0013, \eta_p{}^2 = .39$), but no other main effects or interactions ($ps > .93$). The post-hoc comparisons on the effect of Target Position indicated that sensitivity declined from left to right: sensitivity was higher for targets appearing in the first as compared to the fourth ($\beta = 0.30, t = 2.69, p = .012$) and seventh positions ($\beta = 0.58, t = 5.23, p < .001$), and higher on the fourth than on the seventh position ($\beta = 0.28, t = 2.54, p = .012$, figure 6.2).

To further examine the potential role of suffixes and stems on letter detection strategies, a second Type II ANOVA on the d-prime value across the morphologically complex pseudowords (+stem-suffix and -stem+suffix) was conducted. The analysis of this specific item set also revealed an effect of Target Position ($F(2,58) = 7.25$,

[4]One item was removed from the analysis (included in the target-absent trials of the +stem-suffix pseudowords) because the stem had been mistakenly removed (the included pseudoword was “igeatxu” instead of “ileatxu”).

Table 6.2: Descriptive statistics on sensitivity scores on morphological visual one-back task

Pseudoword condition and sub-condition		**D-prime sensitivity scores by position** 1	4	7
Morphologically Simple				
-stem -suffix	Mean *(SD)*	1.83 (1.22)	1.54 (0.93)	1.24 (1.05)
	Median	1.82	1.45	1.1
	Range	-0.28 – 4.65	0.02 – 3.69	-0.43 – 4.06
Morphologically Complex				
All items	Mean *(SD)*	1.81 (1.01)	1.52 (0.91)	1.25 (0.81)
	Median	1.9	1.64	1.16
	Range	-0.1 – 3.89	0 – 3	-0.18 – 2.8
+ stem -suffix	Mean *(SD)*	1.97 (1.1)	1.48 (0.89)	1.37 (0.88)
	Median	1.84	1.28	1.18
	Range	-0.6 – 3.89	0.18 – 3.71	-0.04 – 3.71
- stem +suffix	Mean *(SD)*	1.81 (1.06)	1.77 (1.3)	1.27 (0.97)
	Median	1.85	1.81	1.3
	Range	0.05 – 3.92	-0.42 – 3.89	-0.39 – 3.29

Note. SD: standard deviation.

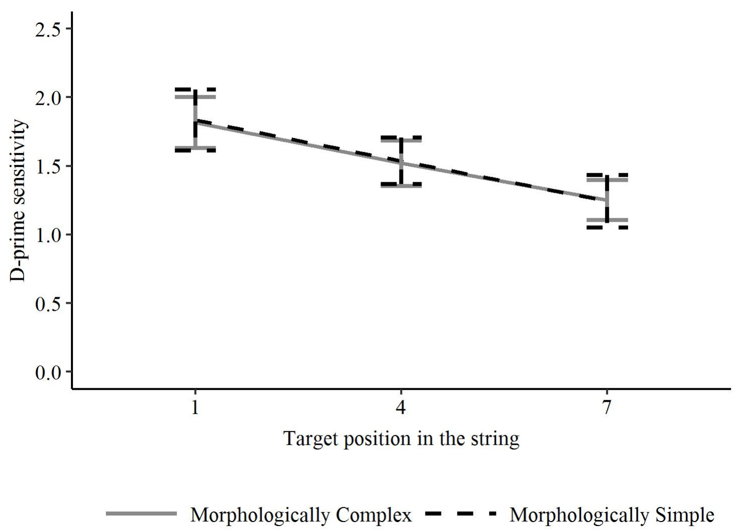


Figure 6.2: Target position effect in the morphological visual one-back task (morphologically complex pseudowords include both +stem-suffix and –stem+suffix items).

p = .0016, η_p^2 = .33), and a trend for a Target Position by Morphological Structure interaction ($F(2,58)$ = 3.14, p = .051, η_p^2 = .15). The post-hoc comparisons on the Target Position by Morphological Structure interaction showed no differences on sensitivity to target letters in each position between the two types of pseudoword (ps > .33). However, within each type of morphological structure, the pattern of sensitivity across target positions differed. For pseudowords including a real stem (+stem-suffix), sensitivity was higher for targets appearing in the first as compared to the fourth (β = 0.49, t = 2.66, p = .0263) and the seventh positions (β = 0.60, t = 3.24, p = .0089), while performance was similar on the fourth and seventh position (β = 0.12, t = 0.59, p = .83). For pseudowords including a pseudo-stem (-stem+suffix), sensitivity was similar for targets appearing in the first and fourth positions (β = 0.04, t = 0.22, p = .82), and in both cases higher than on the seventh position (first - seventh: β = 0.55, t = 2.96, p = .0178; fourth - seventh: β = 0.51, t = 2.74, p = .0263, figure 6.3).

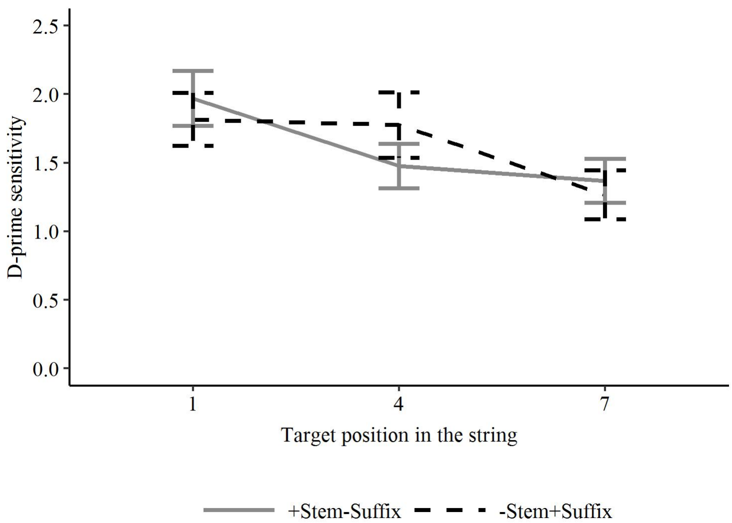


Figure 6.3: Target Position by Morphological Structure interaction in the morphological visual one-back task.

6.3.2 Performance on the morphological visual one-back task and its relation to VA span skills

Additionally, we aimed to explore to what extent general letter detection abilities could be related to letter detection in our experimental morphological letter detection task. We observed that single letter identification was linked to performance on the morphological visual one-back task regardless of the type of pseudoword (*ps* < .05). The other two control variables (age and age-standardised non-verbal intelligence) were not linked to performance. As expected, VA span skills were also linked to performance on the morphological visual one-back task. More specifically, when performance on morphologically complex pseudowords with a pseudo-stem (-stem+suffix) was set as the reference level, there was a significant effect of VA span skills (Intercept = 1.62, β = 3.58 x 10^{-1}, t = 2.24, p = .0316). The interactions between VA span and the type of pseudoword (-stem-suffix/+stem-suffix) showed that the link between VA span and performance on the morphological visual one-back task was significantly different only in the case of morphologically complex pseudowords with a real stem (+stem-suffix). This indicated that, while the effect of VA span was also present when performance on morphologically simple pseudowords (-stem-suffix) was set as the reference level (Intercept = 1.54, β = 3.09 x 10^{-1}, t = 1.93, p = .06), such an effect was not present when performance on morphologically complex pseudowords with a real stem (+stem-suffix) was set as the reference level (Intercept = 1.60, β = 3.98 x 10^{-2}, t = 0.25, p = .81). Thus, better performance on the standard VA span task led to better performance on the morphological visual one-back task in the absence of morphemes and when a pseudo-stem and a real suffix -but not a real stem-was present (figure 6.4).

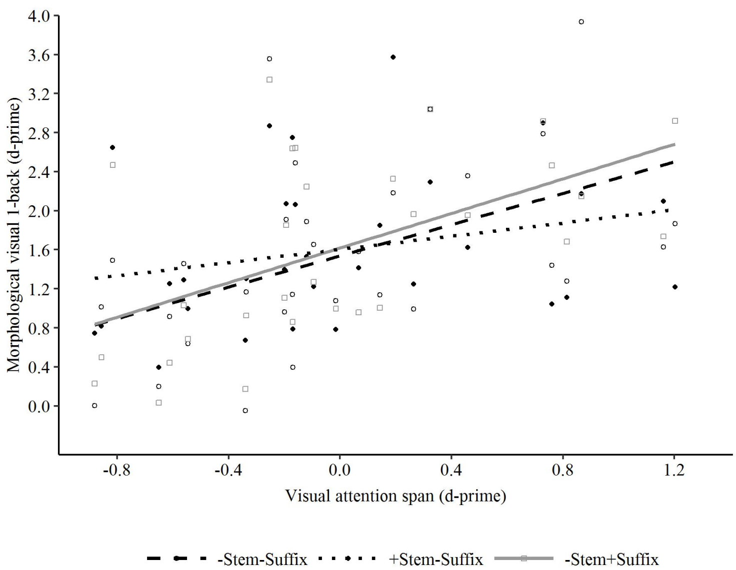


Figure 6.4: VA span skills (centred values) and average performance on the morphological visual one-back task for each type of pseudoword. Points represent by subject average performance by condition, lines reflect regression lines by condition. Control variables are not accounted for in the plot.

6.4 Discussion

The present study aimed to test how the morphological structure of a non-familiar letter string affects the early stages of its orthographic processing; particularly, how the presence of stems and suffixes influences the deployment of visual attention across the string. We considered that the results of this paradigm could shed light on the modulation of orthographic grain size, and thus of VA span demands, when procesing sub-lexical morphemes. Many previous studies have explored the influence of stem/suffix regularities on word identification by manipulating the presence of such regularities in pseudowords (Burani et al., 2002; Casalis et al., 2015; Quémart et al., 2012; Traficante et al., 2011), showing that children are able to visually capture the presence of morphemes during orthographic coding, possibly boosting word recognition. Moreover, recent studies argue in favour of a key role of stems as significant units for lexical access particularly at early ages (Beyersmann, Grainger, et al., 2015; Hasenäcker et al., 2017). Our aim was to explore to what extent children were sensitive to stems and suffixes at the early stages of orthographic processing, exploring the influence of these recurrent regularities in their deployment of visual attention across strings, and thus, in their reading strategy. We tested this in 4th grade Basque children. Because Basque is a very transparent orthography subject to many suffix and composition rules, 4th grade children should have been sufficiently exposed to the orthography as to have internalized most frequent morphemes (Acha et al., 2010). The hypothesis was that if children had internalized these regularities as significant orthographic grains, this might boost the transition towards processing increasingly larger orthographic grains and extracting as much meaningful information as possible within a single fixation. This would in turn modulate the deployment of their VA span across the string of letters.

First, our data support our prediction by revealing that the presence of stems and suffixes tends to modulate the distribution of the visual resources young readers use to process an unfamiliar word. Overall, we observed the expected leftward bias in the distribution mode of the visual attention resources used to identify letters in pseudowords (Lallier, Carreiras, et al., 2013). However, in contrast to our predictions performance on the morphological visual one-back task was similar between morphologically complex and simple pseudowords, and between morphologically complex pseudowords with a real stem and a pseudo-stem. This suggests that the presence of a morpheme did not lead to *better* letter identification performance.

One reason for the apparent absence of “morphological benefit” on performance in this but not previous studies (naming paradigm: Traficante et al., 2011; lexical decision paradigm: Casalis et al., 2015; Quémart et al., 2012; and for a "morphological disadvantage" in letter search see: Beyersmann, Ziegler, & Grainger, 2015) could be the paradigm used. Our task was designed to tap into early letter coding processes and not into lexical access. Thus, the rapid presentation of the letter string could have reduced the influence of morphemes, preventing a processing boost through morphological semantic access. Additionally, the fact that we did not include a real word condition (+stem+suffix) might have boosted sub-lexical effects over lexical ones.

Nevertheless and in support of our hypothesis, when only the items containing orthographic regularities (i.e., morphemes) were examined, we observed that the morphological structure of the complex pseudowords modulated the pattern of letter identification across the string, indicating a distinct influence of stems or suffixes on the deployment of visual attention. For pseudowords including a pseudo-stem and a real suffix (-stem+suffix), attention was directed towards the pseudo-stem since the target letter was identified less accurately in the final position (within the suffix) and more accurately in both the initial and central positions. For pseudowords including a real stem and a pseudo-suffix (+stem-suffix), we observed a more homogeneous spread of attention away from the stem (i.e., across the pseudo-suffix) with similar performance on the central and final positions of the pseudoword.

One explanation for this result might be that stems and suffixes might be processed quite differently. On one hand, real suffixes could be identified early and efficiently as orthographic units (Quémart et al., 2012) through mechanisms such as affix stripping (Taft & Forster, 1975) or chunking (Grainger & Ziegler, 2011), thus freeing cognitive resources for the orthographic processing of the stem (here the pseudo-stem). This would lead to more available visual attentional resources that could be spread homogeneously across the initial and central letters of the pseudoword, hence limiting the left-to-right performance decrease related to reading direction constraints. On the other hand, the identification of real stems at the orthographic level could lead to different effects due to their prominent informative role (e.g., Diependaele et al., 2010; Grainger & Beyersmann, 2017; Taft & Forster, 1975) at the lexical or semantic levels. More specifically, real stem identification could in fact occupy cognitive resources at higher levels of processing such as activating lexical candidates, thus reducing the visual attentional demands for processing the "remaining" right side of the pseudoword. This hypothesis fits well with our findings on the link between VA span skills (measured for consonant strings and thus reflecting a "purer" measure of VA span) and letter identification performance on our morphological one-back task. The analyses revealed that the contribution of VA span skills to performance on the morphological task depended on the presence of real stems in the pseudowords: whereas a significant relation was found between VA span skills and pseudowords without morphemes or pseudowords with a pseudo-stem, this was not the case for pseudowords with a real stem.

The present results are of interest if one considers the contribution of stems and suffixes to word identification in reading development from the perspective of orthographic grains and subsequent variations in visual attention and reading strategies. It has to be noted that these data have been obtained in a sample of Basque children, learning to read a highly transparent and morphologically rich orthography. Questions thus arise regarding whether any influence of stems and suffixes on the deployment of visual attention would be seen in languages of different characteristics. Previous research suggests that the development of sensitivity to morphemes in reading depends on the morphological richness of the language (Casalis et al., 2015; Diamanti et al., 2018). Thus it could be that these facilitative effects would not be seen in children learning a more morphologically simple language. Nevertheless, judging based on our results from the previous chapter this might not be the case since we did not find the robust morphological effects reported in other more morphologically simple languages. Moreover, in languages with deeper orthographies the influence of morphemes could be enhanced due to their additional value in disambiguating pronunciation (J. S. Bowers & Bowers, 2017; Peereman et al., 2013; Rastle, 2018). Cross-linguistic differences of this type would suggest that the internalisation of word structure could be based on different types and sizes of orthographic grains depending on the phonology-morphology-orthography combination of each language. This would fit well with models of reading that consider the influence of the language-orthography combination on the salient orthographic units used in reading (Grainger & Ziegler, 2011; Perry et al., 2007) and the effect of orthographic processing mechanisms on visual aspects of processing such as letter coding (Grainger, 2017). Further work studying the influence of morphemes on reading from the perspective of visual demands is clearly needed to specify the impact of orthographic depth and age on these results. This could shed light on how attentional and orthographic processing strategies cope with the demands of specific languages and their respective orthographies during reading development.

Some of the potential limitations of this study are the sample size and the absence of a cross-sectional design that would have allowed us to study how performance on this task differs depending on reading skill and experience. Another limitation of this study is that knowledge on the characteristics of the used morphemes is based on databases of Basque (Acha et al., 2014; Perea et al., 2006) that do not reflect written exposure to these items during childhood and schooling. To our knowledge, at present such databases do not exist in Basque so we cannot quantify the exposure these children have had to the specific stems and affixes included in the stimuli. A final limitation is that we did not have a separate task testing the children's orthographic knowledge of these morphemes.

Chapter Summary

The key finding of the present results is that the presence of stems and suffixes influences the deployment of visual attention across unfamiliar letter strings in more advanced readers of Basque. This suggests that as children develop, this morphological knowledge might condition their attentional strategies and their reading performance. Particularly the pattern observed for stems (visual attention focused on the stem), could explain the absence of any influence of VA span skills when reading aloud morphologically complex items (presented in the previous chapter).

If the stem acts as a large orthographic grain that occupies attentional resources at higher levels of cognitive processing it could interfere with the assignment of these resources to lexical orthographic processing. The suffix on the other hand could reduce VA span demands but rather than interfere with the orthographic processing of the whole word it could boost it.

All in all, the present findings provide support for the hypothesis that the effects of the presence of morphemes in less skilled readers' performance (Angelelli, Marinelli, De Salvatore, & Burani, 2017; Burani, 2009; Burani et al., 2008; Hasenäcker et al., 2017; Suárez-Coalla & Cuetos, 2013; Suárez-Coalla, Martínez-García, & Cuetos, 2017) could indeed be associated to their influence on visual attentional demands (also see: Burani et al., 2018) that could arise from their status as larger, salient orthographic grains (also see: Law, Veispak, Vanderauwera, & Ghesquière, 2018). They also support the modulation of the visual attention skills involved in orthographic processing, and thus possibly of orthographic grain size by a word's morphological structure.

Part IV

Discussion

Chapter 7

General Discussion

Throughout this thesis we have described how orthographic depth, language and word morphology may modulate the size of the salient orthographic grain used in reading, viewed through the lens of visual attention (VA) span abilities. We have also discussed how the influence of these factors on orthographic grain size may arise at different stages of reading development. The studies included in the present thesis provided further support for the modulation of orthographic grain size based on orthographic depth and morphological complexity, and for the adequacy of the VA span as a measure of orthographic grain size.

Understanding how the aforementioned factors interact influence and interact with reading expertise is relevant to our better understanding of the reading system and particularly to our understanding of how efficient orthographic processing skills, a key component of fluent reading, develop. For the reader, the development of reading expertise and thus efficient orthographic processing is paramount, eventually allowing sight word reading or accessing the most salient/efficient orthographic grain through the mediation of VA span skills and the concurrent construction of a robust orthographic lexicon. For the researcher, understanding this process also allows the identification of the main hurdles developing readers may encounter depending on their individual skills and their language(s), and thus the possibility of understanding which tools/methods could assist the reader in overcoming these hurdles.

In the following sections we will:

- Summarise our main findings.
- Briefly place the findings in the context of the previous literature and suggest future research directions.
- Suggest how the present research could inform educational practice in different language contexts and taking into account the aspect of bilingualism.

7.1 Summary

The present thesis aimed to address two main topics that are pertinent both to furthering research on reading (development) and to understanding how to assist readers who encounter difficulties:

1. The influence of cross-linguistic differences, such as orthographic depth and language morphology, on the processing of larger orthographic grains (assessed through the VA span) in reading and reading-related tasks.
2. The manner in which a word's morphological structure modulates sight word reading, the size of the orthographic grain, and subsequently VA span demands in reading and reading-related tasks.

The first topic was addressed with two cross-linguistic studies while the second was tackled with two sets of experiments in Basque. An overview of the main results of these studies is presented in Table 7.1.

Regarding ***the influence of cross-linguistic differences*** on reading and the orthographic grain size, the results can be grouped into those related to the influence of ***grapheme-phoneme mapping consistency/complexity*** (i.e., orthographic depth) and to those related to the effect of ***other linguistic factors***, possibly related to grapheme-morpheme mapping complexity. The results presented in chapters 3 and 4 showcased the influence of orthographic depth on orthographic grain size and thus the VA span demands in reading and reading-related tasks. Overall, these results indicated that in both monolingual skilled adult readers and bilingual developing readers the influence of learning to read exclusively (monolinguals) or additionally (bilinguals) in a more complex orthography, increased the bias towards processing larger orthographic grains (and words as a whole) and thus VA span demands, particularly when a certain reading expertise is reached.

More specifically, the results of the first study (page 47) demonstrated that early developing readers (in the first two years of formal schooling) who were learning to read in a complex (French) and a simple (Basque) orthography, were similarly biased towards processing larger orthographic grains as early developing readers learning to read in two simple orthographies (Basque and Spanish). In the more advanced group of readers (in the third to fifth years of formal schooling), the former group (French-Basque), were more biased towards larger orthographic grains and whole word processing in two reading-related tasks (one of which was the VA span task). The results overall showed that reading in a more complex orthography, and the subsequent bias to sight word reading and larger orthographic grains, transferred to reading-related tasks, and is likely to also transfer to reading in the other language (Lallier & Carreiras, 2018). These results are in line with previous studies showing: a) the use of larger phonological grains in readers of deeper orthographies (A. W. Ellis, 2004; Katz & Frost, 1992), b) cross-linguistic transfer in bilingual reading (Durgunoğlu, 2002), and c) the modulation of orthographic grain size in bilinguals, with reading in a more complex and less consistent orthography leading to an increase in the orthographic grain size (Lallier & Carreiras, 2018).

The results of the second study (page 71) with the adult skilled readers did not show consistent differences between the L1 French, Spanish and Basque groups in their VA span skills, possibly due to the fine tuning of letter processing skills as a result of reading experience, or due to the task used not being sensitive enough to capture the influence of cross-linguistic differences on the visual grain size for skilled readers. Nevertheless, reliance on larger orthographic grains (and on sight word reading) for readers of the more complex orthography (French), was further supported by the correlation between VA span skills and text reading performance in readers of French but not Spanish (regarding Basque see below). This second study in skilled reader adults is also informative regarding whether other linguistic factors beyond orthographic depth can influence the bias towards larger orthographic grains in reading. As aforementioned, the results of this study showed no differences in the VA span skills of the skilled adult readers of French, Spanish and Basque. Still, VA span skills correlated with reading skills for readers of French and Basque, but not Spanish. If the cross-linguistic differences were related only to orthographic depth, VA span skills should not correlate with reading skills neither for readers of Basque nor for readers of Spanish (both orthographies are consistent and present similarly simple grapheme-phoneme mappings). The correlation between VA span skills and text reading in the adult skilled readers of Basque indicated that other factors might have mediated this relation. We suggest that the agglutinative nature of Basque, and subsequent differences in word length and morphological structure could be the source of this difference, possibly increasing the bias towards processing larger orthographic grains (and words as a whole), particularly for more skilled readers. There is some evidence that the contribution of skills related to reading development in alphabetic orthographies with consistent grapheme/phoneme mappings may depend on whether they are agglutinative (Georgiou, Torppa, et al., 2012; Landerl et al., 2013; Moll et al., 2014; Ziegler, Bertrand, et al., 2010), thus suggesting that this characteristic could lead to other cross-linguistic differences in reading.

Table 7.1: Summary of studies and main results

Study	Participants	Tasks	Main results
Cross-linguistic studies			
Study 1	• French-Basque, Spanish-Basque bilinguals • early and advanced developing readers	• VA span (visual one-back) • RAN (consonants, non-words, words)	• Advanced French-Basque readers spread attention homogeneously across the consonant string in the VA span task, and were influenced by the presence of words in the word RAN task. Both results indicate a larger bias towards multi-letter processing in this group as compared to the Spanish-Basque bilinguals.
Study 2	• L1 French, Spanish and Basque • adult skilled readers	• VA span (Global and Partial report) • Text reading	• The three groups showed similar patterns of VA span performance, although the L1 Basque group performed the partial report task more accurately than the L1 French group. • Better VA span skills correlated with more fluent text reading in the L1 French and Basque groups. This indicates that orthographic grain size and thus VA span demands could be influenced both by orthographic depth and other cross-linguistic differences, e.g. agglutination.
Studies in Basque			
Study 3	• L1 Basque • early and more advanced developing readers	• VA span (visual one-back) • Morphological naming task	• A “morphological benefit” was found in naming accuracy (complex items read more accurately than simple items): for early readers the benefit was in words and for advanced readers it was in pseudowords. • Better VA span skills were related to larger lexicality effects (i.e., the efficiency of sight word as opposed to sub-lexical reading) in naming speed only in the absence of sub-lexical morphemes.

Continued on the next page

Table 7.1: Summary of studies and main results

Study	Participants	Tasks	Main results
Study 4	• L1 Basque • advanced developing readers (same as in Study 3)	• VA span (visual one-back) • Morphological visual one-back task	• The presence of a morpheme did not lead to better letter detection performance in the morphological visual one-back task. Nevertheless, the presence of stems and suffixes differently modulated the deployment of visual attention across unfamiliar letter strings. • VA span skills correlated with performance on the morphological visual one-back task only when the stimuli were pseudowords either with no real morpheme or with a real suffix, but not with a real stem.

Regarding ***the influence of a word's morphological structure*** on reading and orthographic grain size, the results of the two studies in Basque are pertinent. Overall, the results of these studies indicated that the presence of sub-lexical morphemes modulated the VA span demands for reading and orthographic processing in developing readers, particularly when a certain level of reading expertise was reached. Namely, the results of the third study (page 87) indicated that for early developing Basque readers (in the second year of formal schooling) orthographic grain size was not modulated by the presence of morphemes, possibly due to their reliance on smaller orthographic grains. In the more advanced readers (in the fourth year of formal schooling), the presence of sub-lexical morphemes influenced orthographic grain size, removing any influence of VA span skills on reading, possibly because morphemes acted as a salient larger sub-lexical orthographic grain that reduced VA span demands. Indeed a masked priming study on adult skilled readers and readers with dyslexia suggested that readers with dyslexia may rely strongly on sub-lexical morphemes in reading particularly at the orthographic level of processing (Law et al., 2018). The authors of this study also suggested that this could result from the use of morpho-orthographic grains reducing visual-attentional processing demands. Thus it is likely that morphemes can be used as salient large orthographic grains in reading, reducing VA span demands.In the fourth and final study (page 109), the results indicated that the presence of sub-lexical morphemes in unfamiliar words can influence the deployment of visual attention across the orthographic string in advanced readers (readers in fourth grade). More specifically, although the presence of real morphemes did not boost performance on our one-back letter detection task, the deployment of visual attention across the string was differently modulated when a familiar stem, as opposed to a familiar suffix, was encountered. More precisely, our results indicated that stem identification was prioritized (also in line with importance of the stem Grainger & Beyersmann, 2017; Lázaro, Illera, & Sainz, 2018), which reduced visual attention deployment across the remaining letters.

Some of the limitations of our studies were presented in their respective chapters. Overall, most of our studies were limited by their sample size, while the studies on developing readers were also limited by the absence of additional groups of readers with more reading expertise (for example children in the sixth grade). Given our findings we also consider that changing our paradigms (e.g., adding more conditions to the letter search) could have improved our design, or adding finer grained measures, such as eye-tracking or voice onset. Finally, it would have been of interest to test our morphological paradigms with some additional populations. For example, the performance of Spanish-Basque and French-Basque bilinguals on the morphological naming task and the morphological one-back task could test whether the bias towards larger orthographic grains in the latter group would modulate their use of morphemes in reading. Another option would be to test L1 Basque children with reading difficulties, particularly with a VA span deficit, to directly observe whether they would rely on morphological information more than typically developing readers. The following section aims to briefly place the results of the present thesis in the context of current research in the field of reading development and suggest how research in this direction could translate into practice in the future.

7.2 General conclusions and outstanding questions

7.2.1 VA span and orthographic grain size: modulations based on phonology-orthography-semantic mappings

The aforementioned studies provide support for the modulation of orthographic grain size based on orthographic depth and morphological complexity, and the adequacy of the VA span as a measure of orthographic grain size. More specifically, our results indicated that larger orthographic grains, and thus higher VA span demands were associated with: a) reading in a deeper orthography with more complex grapheme-to-phoneme mappings, and b) with the presence of less semantic (morphological) information at the sub-lexical level. The results supporting that reading in a deeper orthography leads to reliance on larger orthographic grain sizes are in line with those of previous studies that have also demonstrated either enhanced VA span skills or a more important role of VA span skills in reading for readers of more complex and less consistent orthographies (Awadh et al., 2016; Lallier et al., 2016; Lallier & Carreiras, 2018; Lallier, Carreiras, et al., 2013). Our results indicating that the presence of less morphological information sub-lexically also leads to processing larger orthographic grains provide a new perspective in the study of morphemes in reading development. These results are in line with studies supporting VA span skills are critical to the acquisition of orthographic knowledge (Bosse et al., 2013; Lallier et al., 2014), and thus could be less relevant when sub-lexical morphological grains (already represented in the lexicon) are available. Moreover, it is in line with studies indicating that the presence of morphological information at the sub-lexical level influences word processing, possibly affecting the performance of less skilled readers, who due to their reduced visual-orthographic processing skills, are prone to rely more on morphological information (Medeiros & Duñabeitia, 2016).

Our results raise further questions regarding whether the effects of orthographic depth and morphological complexity on orthographic grain size could interact. A first question would be whether the bias towards processing larger orthographic grains in a deeper orthography, and thus towards the stronger contribution of VA span skills to reading, would be reduced when complex or inconsistent grapheme-phoneme mappings are embedded in morphemes. This could be expected both based on our results, and given that in some languages grapheme-morpheme mappings can disambiguate grapheme-phoneme mapping complexity (J. S. Bowers & Bowers, 2017; Frost et al., 1987; Peereman et al., 2013; Rastle, 2018). Moreover, this hypothesis could find support in the lexical quality hypothesis (Perfetti & Hart, 2002) that would suggest that an increased robustness in the connections between semantics-orthography-phonology (expected due to the presence of sub-lexical morphemes) could increase the overall quality of the lexical representation, influencing reading performance.

Our results also raise questions regarding how orthographic grain size and the role of the VA span in reading could be modulated by the presence of semantic information at the sub- or supra-lexical level. Reliance on semantic (morphological) information at the sub-lexical level has been observed particularly in less skilled readers (Burani et al., 2008; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013) and according to our results could be related to reduced VA span demands in orthographic processing. A second question that could be addressed in future work, is whether similar effects could be found at the supra-lexical level. More specifically, it would be of interest to study whether reliance on semantic information at the supra-lexical level, for example in text reading, could also influence the visual-attentional demands of orthographic processing. The results of a previous study in a Arabic suggest that VA span skills were related to reading in a more opaque script (non-vowelized) for readers who relied more heavily on top-down semantic processing (Lallier et al., 2018). The results cannot be linked intuitively to those of our study. Still, it could be the case that reduced visual-attentional resources could drive readers to rely more on contextual top-down information as a compensation mechanism, similarly to what has been suggested for sub-lexical morphological information (Law et al., 2018).

7.2.2 Reading development in alphabetic orthographies: studying the influence of the word's morphological structure

Our results support the role of morphemes as accessible units during reading development (Burani et al., 2008; Hasenäcker et al., 2017), particularly highlighting that the effects of sub-lexical morphemes on reading could go beyond semantics and interact with visual processing demands (at least as reading expertise increases, also see: Grainger & Beyersmann, 2017, for a review on the influence of morphemes at the orthographic level and a hypothesis regarding why it appears in more advanced stages of reading development). On the one hand, this is in line with the aforementioned study on adult readers with dyslexia (but good reading comprehension skills) who were more sensitive to morphemes at the early orthographic level of processing than skilled readers, suggesting sensitivity to morphemes at the orthographic level could constitute a compensation mechanism that reduces visual processing demands (Law et al., 2018). On the other hand, it has been suggested that for young readers with dyslexia, the influence of morphemes in reading is modulated by their length (concretely that of the stem), as a result of visual limitations on processing (Burani et al., 2018), so this would suggest that not all morphemes could act as useful larger orthographic grains for readers with dyslexia. Still, both these (Burani et al., 2018; Law et al., 2018) and our own studies, highlight the influence of morphemes on visual orthographic processing. Eye-tracking data are also in line with our results, showing that the the effects of morphological complexity are also reflected by eye movements, for example that initial fixation position within a word depends on its morphological structure (Farid & Grainger, 1996; Hyönä et al., 2018; Yan et al., 2014). Overall, these results suggest that morphemes influence the visual-attentional resources required in reading, although further research is needed in order to determine in which cases their presence boosts or hinders performance, modulating orthographic grain size and reducing or increasing VA span demands.

We also believe that further research focusing on the role of morphemes in reading development could apply a more global perspective, accounting for individual abilities related to morphological knowledge at both the level of oral-linguistic (e.g., morphological awareness) and written-orthographic (e.g., orthographic knowledge of morphemes, spelling). This would allow an understanding of the degree to which developing sensitivity to morphemes, firstly at the semantic and subsequently at the orthographic level, depends on linguistic skills at the level of oral language, visual orthographic skills, or both. For example, morphological awareness was found to be related only to morpho-semantic, and not to morpho-orthographic, processing in adults with dyslexia (Law et al., 2018), while in a study in Chinese, VA span skills were correlated with morphological awareness (Zhao et al., 2018a). Disentangling the effects of these different factors could also clarify which factors can be trained to support the development of fluent reading.

7.2.3 The transition from serial to parallel processing during reading development

A recurrent finding from our studies (cf., study 1 and 3) is that readers' ability to process larger orthographic units increases in parallel with reading expertise (also see: van den Boer & de Jong, 2015), possibly reflecting a shift from serial to parallel processing for letter strings occurring during reading development. In particular, the results of study 1, showing that the cross-linguistic differences were found in VA span and RAN performance only in the advanced readers, support the hypothesis that these two reading-related tasks are consistently associated with reading skill across development because they also reflect the aforementioned shift from serial to parallel processing (regarding the RAN this was suggested by: Protopapas et al., 2013). If this is the case, the strength of the association between VA span, RAN, and reading skills could be modulated both by the grain size prompted by the presented stimulus (word: single large grains, pseudoword: multiple small grains, text: multiple large grains) and the developmental stage of reading (early, advanced, skilled, e.g., van den Boer & de Jong, 2015).

These results also highlight that processes of reading that relate to larger orthographic grains should be addressed and assessed after the first years of schooling, when readers have transitioned to more parallel processing, even for readers of consistent orthographies. This is in favour of Rastle (2018)'s suggestion that the influence of some factors (in that case morphemes) on reading may be understated in the reading development literature due to our overall focus on the first couple of years of reading acquisition.

7.3 From theory to practice

Our results cannot be directly translated into educational practice, yet we believe that they could inspire research on future methods/approaches that could help literacy instruction.

More specifically, we consider that our studies could inform certain teaching methods that aim to boost the establishment of a robust orthographic lexicon. Based on our findings this could be achieved through the following approaches:

- ***Focusing on larger orthographic grains (including morphemes)*** and thus increasing the robustness of lexical orthographic representations and the efficiency of orthographic learning (Tucker, Castles, Laroche, & Deacon, 2016), possibly regardless of orthographic depth. In particular, a focus on morphemes that are efficient reading units (Burani et al., 2008; Hasenäcker et al., 2016) could decrease visual and orthographic processing demands and thus support readers with dyslexia (Law et al., 2018). Focusing reading instruction on learning grapheme-morpheme mappings was recently suggested for readers of English (J. S. Bowers & Bowers, 2017). Still, it was highlighted by Rastle (2018) that there are a number of issues that should be taken into account before morphological instruction becomes a core component of literacy instruction. We consider that this could be true in other languages beyond English. Firstly, it would be necessary to better understand the developmental trajectory of morphological processing in reading, and also to determine *when* during reading development children begin to encounter large numbers of morphologically complex words. This would allow an estimation of the relative benefit of morphological instruction (Rastle, 2018). Finally, the degree to which focusing on morphemes would benefit the reader could also depend on the salience of morphological information in the spoken language, which would affect one's sensitivity to morphological information even in the absence of formal instruction (Diamanti et al., 2018; Duncan et al., 2009), and on the degree to which morphology is consistently represented in written language (the consistency of grapheme-morpheme mappings: Rastle, 2018).

- Another approach to boosting the orthographic lexicon would be through ***training VA span skills*** that support the acquisition of lexical orthographic representations. One option would be to improve VA span skills with software aiming to enhance multi-element processing (Valdois, Bosse, & Peyrin, 2013). However, further research would be needed to support the efficiency of this training method.

We also consider that our studies bear certain relevance in relation to ***bilingual education***, and particularly to bilingual education in the Spanish region of the Basque Country. We consider that bilingualism overall is an asset, yet it is possible that the degree of overlap between Spanish and Basque at the level of grapheme-to-phoneme mappings, and the subsequent ease with which accurate decoding can be achieved simultaneously in both languages, may lead us to underestimate the hurdles readers encounter. We particularly believe this could be the case when the language in which bilinguals predominantly learn to read does not coincide with their dominant oral language (e.g., Spanish as the native and unique language spoken at home, and Basque as the main language used at school, although Cenoz and Valencia (1994) report advantages for these bilinguals when tested on their knowledge of a third language as young adults).

First, the salience of morphemes as reading units and the resulting modulation of VA span demands found in studies 3 and 4, highlights the relevance of connecting orthographic grains to linguistic units of meaning when reading. The ability to process morphemes during reading and to develop morpho-orthographic representations (Grainger & Beyersmann, 2017) could be delayed for bilinguals learning to read in the language they have less exposure to orally (and in which they may have fewer and/or less robust morpho-semantic representations). This could interfere with the development of fluent reading skills and particularly with reading comprehension, despite timely development of decoding accuracy. For example, it has been reported that second language readers with similar decoding skills as first language readers, were worse in reading comprehension (Verhoeven, Voeten, & Vermeer, 2018). The authors suggested that this disadvantage resulted from second language readers' lower lexical quality (measured in this study through speech decoding, morphological knowledge and vocabulary). Arguably, this could also be the case for bilinguals if exposure and proficiency in their non-dominant language is not sufficiently high (also see: Cummins, 1979). Regarding second language reading, Nagy and Anderson (1999) suggested that an important aspect in learning to read fluently is to be able to capitalise on meta-linguistic awareness (boosted by bilingualism depending on the language combination: Bialystok, McBride-Chang, & Luk, 2005; Reder, Marec-Breton, Gombert, & Demont, 2013, and related to bilingual reading skills: e.g., morphological awareness Wang, Ko, & Choi, 2009) and to be able to transfer knowledge of one language to the other (as found in: Bialystok, Luk, & Kwan, 2005; Durgunoğlu, 2002) in order to compensate for possible difficulties. This ability would also rely on a certain degree of proficiency in the non-dominant language in order to be successful. The second aspect of our results that could be relevant to this issue is the difference in the reliance on VA span skills between skilled readers of Basque and Spanish when reading (present in the former but not the latter, see study 2). This difference suggests that the similarity of the two languages with regards to grapheme-phoneme mappings does not ensure the similar contribution of some of the reading-related cognitive processes to reading in the two languages.

Overall, we consider that the issues discussed in the previous paragraph could be of relevance in the context of ***bilingual education*** primarily in two cases: a) if the individual has reading difficulties, and/or b) if the individual is not sufficiently exposed to reading material in their dominant spoken language. In both cases, the individual would be less likely to attain fluent reading skills in either of the two languages, with consequences impacting their education down the line. Further research would be necessary in order to understand the difficulties that bilinguals come across when their dominant language and the main language of reading instruction differ and which tools would allow them to progress to become fluent readers and comprehenders.

7.4 Conclusion

The present thesis aimed to further investigate the modulation of orthographic grain size and VA span demands in reading based on three main factors: orthographic depth, morphological complexity and reading expertise. Our results indicate that all the aforementioned factors influence the orthographic grain size used in reading measured mainly through the contribution of VA span skills to reading development.

We believe that ***reading expertise*** can determine whether the influence of the other factors is observable in reading. More specifically, since early readers can only process smaller orthographic grains it is unlikely to observe further modulations of orthographic grain size based on orthographic depth or morphological complexity. After a certain degree of reading expertise is attained, ***orthographic depth*** increases orthographic grain size also increasing VA span demands. Finally, ***morphological complexity*** influences the availability of large orthographic grains, with the presence of sub-lexical morphemes reducing VA span demands; an effect that we showed might be specifically related to the presence of stems.

The results of the present thesis, despite their limitations, are of relevance to future research in reading development, particularly in relation to the acquisition of orthographic knowledge and the subsequent availability of sight word reading and processing large orthographic grains. Our studies have highlighted how orthographic grain size is modulated by reading expertise, orthographic depth and their interaction. They have also highlighted the influence of morphological complexity both within and between languages on reading and especially on the orthographic grain size. The study of the influence of these factors on reading, viewed under the new perspective of the modulation of orthographic grain size (Grainger & Ziegler, 2011; Lallier & Carreiras, 2018), offers another avenue to investigate the visual demands and limitations imposed on orthographic processing during reading development and skilled reading. Future work should strive to further understand the interactions between all these factors (grapheme-phoneme mappings, grapheme-morpheme mappings, reading expertise) and their effects on the salience and availability of sight word reading and larger orthographic grains in different languages with alphabetic orthographies.

Resumen amplio en castellano

La identificación de palabras escritas es una tarea cotidiana para cada lector. El proceso para realizar esta tarea puede variar mucho de un individuo a otro. Los adultos con fluidez lectora leen información de manera casi inconsciente mientras caminan por la calle: los nombres de las calles, los préstamos bancarios, las ofertas del supermercado, los próximos conciertos, etc. Los niños que están en el umbral del mundo lector no pueden ejecutar esta tarea sin esfuerzo y a veces incluso necesitan pararse en mitad de la calle para conseguir leer, lentamente y con mucha concentración, alguna palabra que haya llamado su atención. Esta diferencia ilustra que es más probable que las palabras se procesen como una unidad (un proceso que se llama lectura léxica, visual o directa) en el caso de los lectores más fluidos, cuya habilidad de procesamiento ortográfico se ha afinado con el apoyo de sus habilidades visuales y lingüísticas. Para que los lectores menos fluidos puedan leer correctamente las palabras desconocidas es necesario descomponer la palabra en unidades o granos ortográficos más pequeños (lectura subléxica). En caso de que la palabra no se pueda procesar como una sola unidad, el tamaño del grano ortográfico en el que se descompone dependerá de los factores anteriormente mencionados (ej., la fluidez lectora, la capacidad de procesamiento visual/ortográfico), pero también podrían influir otros como la manera en la que los granos ortográficos de la palabra se corresponden con sonidos (fonología) y su significado (semántica). El presente trabajo tiene como objetivo identificar cómo el tamaño del grano ortográfico que corresponde a una unidad lingüística de sonido (fonemas) o de significado (morfemas), y la consistencia de estas correspondencias, puede interactuar con el procesamiento visual y ortográfico de las palabras en lectores de varios niveles de fluidez.

Las teorías sobre el desarrollo de la lectura dan una descripción detallada de cómo se desarrolla el lector incrementando gradualmente su habilidad para leer palabras y procesar unidades o granos ortográficos más grandes (Ehri, 2005; Frith, 1985; Share, 1995). El primer paso en la enseñanza formal de la lectura es el aprendizaje de las correspondencias entre grafemas y fonemas (CGF). Algunas de las CGF se aprenden más rápido permitiendo que el lector identifique palabras cortas basándose solo en algunas letras; así, el lector va aprendiendo las representaciones ortográficas de las palabras. Cuando se han adquirido todas las CGF, el lector aprende rápidamente a leer muchas más palabras y mejora su procesamiento ortográfico, incrementando el número de representaciones léxico-ortográficas que conoce. Una vez posea un amplio inventario de representaciones ortográficas de las palabras, el lector ya puede leer utilizando la vía léxica o directa, un proceso clave en la adquisición de la fluidez lectora. Al mismo tiempo, los lectores también se ven capaces de procesar unidades o granos ortográficos más grandes en palabras desconocidas que solo se pueden procesar de manera subléxica. Esta habilidad resulta del afinamiento del procesamiento ortográfico del lector a las características de la ortografía del idioma. Dicho afinamiento se produce por la extracción de reglas y regularidades de su gran inventario de representaciones ortográficas de palabras conocidas.

De este modo, tanto la capacidad lectora como la familiaridad de una palabra determinan si el lector utilizará la vía léxica o directa para procesar una palabra, así como el tamaño del grano ortográfico al que recurrirá si utiliza la vía sublexica. Otros parámetros importantes que definen el tamaño de las unidades ortográficas que destacan en la lectura son la complejidad y la consistencia de las CGF (Frost et al., 1987). Una mayor complejidad e inconsistencia de las CGF lleva al lector a depender del procesamiento de granos ortográficos y fonológicos más grandes para leer correctamente y con fluidez (Ziegler & Goswami, 2005). Por tanto, los lectores que leen en ortografías más complejas y menos consistentes dependen más de la vía léxica y también del procesamiento de unidades ortográficas más grandes cuando utilizan la vía subléxica. Otro parámetro que puede afectar tanto a la lectura léxica como al tamaño del grano ortográfico en la lectura subléxica es la correspondencia entre los granos ortográficos y las distintas unidades lingüísticas con significado (morfemas): se ha demostrado que para los lectores menos fluidos la presencia de morfemas dentro de una palabra (es decir, a nivel subléxico) ayuda a su procesamiento, ya que los morfemas se emplean como unidades ortográficas destacables que apoyan la lectura (Angelelli et al., 2017; Burani, 2009; Burani et al., 2008; Hasenäcker et al., 2017; Suárez-Coalla & Cuetos, 2013; Suárez-Coalla et al., 2017).

En el presente trabajo, el intervalo de atención visual (visual attention span) se emplea para evaluar en qué medida utiliza el lector la vía léxica en la lectura, así como el tamaño del grano ortográfico que usa en la vía subléxica. El intervalo de atención visual sirve como medida de los recursos visuales perceptivos y atencionales y refleja el número de elementos visuales distintos que se pueden procesar simultáneamente dentro de una matriz multielemento (Bosse et al., 2007). En el contexto de la lectura, el intervalo de atención visual se asocia al número y/o tamaño de las unidades ortográficas que se pueden procesar de un vistazo (Bosse & Valdois, 2009; Frey &

Bosse, 2018). Algunos estudios han demostrado la asociación entre el intervalo de atención visual y la lectura tanto en individuos con dislexia (Bosse et al., 2007; Dubois et al., 2010; Germano et al., 2014; Lallier et al., 2014; Lobier et al., 2014; Valdois et al., 2003; Zoubrinetzky et al., 2014) como en lectores típicos (Awadh et al., 2016; Bosse et al., 2014; Bosse & Valdois, 2009; Lobier et al., 2013; Prado et al., 2007; van den Boer et al., 2014, 2015; Zhao et al., 2017). El presente estudio se centra en el intervalo de atención visual como medida, debido a su papel en la adquisición de representaciones léxico-ortográficas (Bosse et al., 2013; Lallier et al., 2014; van den Boer et al., 2015), la lectura por vía léxica (Bosse et al., 2007; Bosse & Valdois, 2009) o la habilidad para procesar granos/unidades ortográficas grandes (Lallier, Carreiras, et al., 2013). En el presente trabajo se utiliza el intervalo de atención visual para investigar dos temas:

- La influencia de las diferencias lingüísticas en el tamaño del grano visual y ortográfico de la lectura, reflejado por el intervalo de atención visual de los lectores.
- La manera en la que la estructura morfológica de la palabra modula la lectura por vía léxica/el tamaño del grano ortográfico y, como consecuencia, la demanda de recursos visuoatencionales en la lectura y tareas relacionadas con la lectura.

Las cuestiones anteriores se abordan en cuatro estudios. Los dos primeros investigan el primer tema comparando lectores con diferencias en cuanto a los idiomas en los que leen. Los dos últimos estudian el segundo tema con lectores que leen en un idioma, el euskera. Tanto el primer como el tercer estudio ofrecen una perspectiva evolutiva, incluyendo lectores tempranos y más avanzados en un estudio transversal. Por tanto, investigan también cómo el desarrollo de la capacidad lectora podría interactuar con los otros factores estudiados, influyendo en la lectura léxica y el tamaño del grano visual y ortográfico. Aparte del euskera, los demás idiomas que se estudian en el primer y el segundo estudio translingüístico son el castellano y el francés. En resumen, los estudios se centran en el intervalo de atención visual en la lectura y cómo su papel se puede modular reflejando diferencias en el tamaño del grano ortográfico que, a su vez, se ve influido por otros factores estudiados: la consistencia entre la asociación de los grafemas con los fonemas del idioma, la riqueza morfológica, la estructura morfológica de la palabra y su familiaridad y la capacidad lectora del individuo.

Estudio 1: El efecto de la consistencia ortográfica en el intervalo de atención visual y el nombramiento rápido automatizado.

El estudio investiga si una mayor inconsistencia y complejidad ortográfica pueden incrementar el sesgo hacia el procesamiento de muchas letras en paralelo en dos tareas relacionadas con la lectura: el intervalo de atención visual y el nombramiento rápido automatizado. Como se ha mencionado anteriormente, el incremento de la complejidad de las correspondencias entre grafemas y fonemas que se observa en ortografías menos consistentes lleva a los lectores a depender de unidades o granos ortográficos y fonológicos de mayor tamaño (Ziegler & Goswami, 2005). La novedad de este estudio se encuentra en que no observamos estas diferencias directamente en la lectura sino en tareas relacionadas con la lectura que incluyen procesamiento visual u ortográfico. Además, en la tarea de nombramiento rápido automatizado incluimos una manipulación nueva (algunas secuencias de letras formaban palabras frecuentes en euskera). En este experimento participaron niños y niñas bilingües de castellano-euskera y francés-euskera, entre los que se incluían lectores tempranos (30 niñas/niños en primero y segundo de primaria) y más avanzados (24 niñas/niños en tercero, cuarto y quinto de primaria). Estudiamos si el sesgo hacia el procesamiento de mayor cantidad de letras en paralelo sería diferente en los participantes como resultado de estar aprendiendo a leer en dos ortografías consistentes (castellano, euskera) o una ortografía consistente y otra menos consistente (euskera, francés). Se esperaba que los bilingües de francés y euskera, que leen también en una ortografía menos consistente (francés), dependieran de granos/unidades ortográficas de mayor tamaño en la lectura y, como consecuencia, también tuvieran un sesgo mayor hacía el procesamiento de múltiples letras en paralelo en ambas tareas. Eso se reflejaría por: (a) una distribución uniforme de la atención medida en la tarea del intervalo de atención visual y (b), una mayor interferencia de las palabras frecuentes incluidas en la tarea de nombramiento rápido automatizado, ralentizando el desempeño de la tarea.

Los resultados seguían el patrón esperado en los lectores más avanzados (de tercero, cuarto y quinto de primaria) indicando que leer en francés, una ortografía menos consistente, conducía a un mayor sesgo hacía el procesamiento de múltiples letras en paralelo tanto en la tarea del intervalo de atención visual como en la tarea de nombramiento rápido automatizado (con la inclusión de palabras frecuentes). Es necesario corroborar estos resultados con muestras más grandes para especificar hasta qué punto pueden afectar tanto la inconsistencia ortográfica como la experiencia lectora bilingüe al sesgo hacia el procesamiento de mayores unidades ortográficas y, como resultado, hacia múltiples letras en paralelo tomando en cuenta el tiempo que se dedica a leer en cada idioma. Estudios translingüísticos de este tipo podrían arrojar luz sobre las dificultades a las que se enfrentan los lectores bilingües cuando aprenden a leer en los dos idiomas, pero también en cuanto a los recursos disponibles para compensar sus dificultades.

Estudio 2: El intervalo de atención visual en la lectura fluida: efectos de la ortografía y de la morfología de los idiomas.

El objetivo del segundo estudio era investigar qué otros factores podrían influir en el papel del intervalo de atención visual en la lectura adulta. Observamos a lectores adultos de tres ortografías alfabéticas: dos consistentes (castellano, euskera) y una menos consistente (francés). En base a los resultados del primer estudio, se esperaba que el grupo de lectores franceses tuviera un intervalo de atención visual mayor (una distribución más uniforme de recursos visuoatencionales) o que el intervalo de atención visual estuviera más relacionado con la capacidad lectora en francés (Lallier et al., 2018, 2016; Lallier, Carreiras, et al., 2013). Asimismo se esperaba que cualquier diferencia entre el grupo de lectores de euskera y de castellano no se pudiera atribuir a la consistencia ortográfica, ya que ambos idiomas tienen una ortografía consistente. De ese modo, las diferencias estarían relacionadas con otras características. Por ejemplo, una característica del euskera que el castellano no comparte, y que podría provocar diferencias en el papel del intervalo de atención visual en la lectura, es la relevancia de las unidades morfológicas, y la presencia de palabras más largas como resultado de la morfología aglutinante del euskera.

Los resultados indicaron un patrón de distribución de atención visual parecido en los tres grupos, lo que apunta a que no habría diferencias en el desempeño de esta tarea en los lectores adultos en cuanto al tamaño de grano ortográfico que se usa en la lectura. Sin embargo, se observó una diferencia entre los lectores de euskera y de francés lo que sugiere que, aunque los lectores de una ortografía menos consistente son capaces de procesar más letras en paralelo, es posible que los lectores de ortografías más consistentes tengan una capacidad más fina para codificar la posición de cada letra. Estudios futuros podrían aportar más pruebas para apoyar esta hipótesis. Finalmente, la asociación entre la capacidad lectora y el intervalo de atención visual en los lectores de francés y euskera pero no en los lectores de castellano indican que el tamaño del grano ortográfico puede modularse debido a factores lingüísticos más allá de la consistencia ortográfica. Más específicamente, consideramos que el tamaño del grano ortográfico y el papel del intervalo de atención visual podrían depender de la aglutinación lingüística y la subsiguiente mayor longitud de las palabras en euskera. Sin embargo no podemos excluir otros factores que caracterizan la morfología del idioma.

Estudio 3: El intervalo de atención visual y la estructura morfológica de los estímulos ortográficos.

El segundo estudio introdujo, mediante una perspectiva translingüística, la idea de que la estructura morfológica del idioma podría influir en el tamaño del grano ortográfico y el papel del intervalo de atención visual. En este estudio cambiamos el enfoque estudiando la estructura morfológica al nivel de la palabra (y no del texto) y a la lectura en un solo idioma, el euskera. Estudiamos si el vínculo entre el intervalo de atención visual y la lectura se modula por la presencia de morfemas. La muestra de participantes, que constaba de niñas y niños de segundo y tercero de primaria con el euskera como su lengua nativa, nombraron en voz alta palabras y pseudopalabras morfológicamente simples (constituidas por un morfema) o complejas (constituidas por dos morfemas). Además, medimos su intervalo de atención visual. Nuestros resultados demostraron que todos los lectores eran sensibles a la presencia de los morfemas cuando no conocen una palabra y, por ende, utilizan la vía subléxica de la lectura. Asimismo, observamos que el papel del intervalo de atención visual en la lectura se modula por la presencia de morfemas solo en los lectores avanzados. Específicamente, observamos que en los lectores avanzados el intervalo de atención visual influía la lectura de estímulos simples pero no de estímulos complejos. Esto podría sugerir que la influencia de los morfemas al nivel ortográfico requiere cierto grado de fluidez lectora (Grainger & Beyersmann, 2017).

Estos resultados son acordes con los del primer estudio, que también destacaron las diferencias en el tamaño del grano ortográfico que se usa en la lectura (modulado por la consistencia ortográfica en aquel caso) solo en lectores más avanzados. Los estudios futuros sobre la influencia de los requisitos visuoatencionales en el desarrollo de la capacidad lectora deberían explorar tanto el efecto de la consistencia ortográfica como de la complejidad morfológica, a fin de entender los obstáculos con los que se enfrentan los lectores en diferentes idiomas (Diamanti et al., 2018).

Estudio 4: La influencia de las raíces y los sufijos en la distribución de la atención visual sobre los estímulos ortográficos.

El tercer estudio indicó que los lectores del euskera desarrollan una sensibilidad a los morfemas y que, particularmente para los lectores más avanzados, esta sensibilidad influye el tamaño del grano ortográfico y el papel del intervalo de atención visual en la lectura. La ausencia de un efecto del intervalo de atención visual en la lectura cuando hay morfemas a nivel subléxico plantea dudas sobre cómo los morfemas influyen en la distribución de la atención visual sobre las cadenas ortográficas, y si las raíces y los sufijos podrían tener efectos diferentes. El tercer estudio tiene como objetivo responder a esta pregunta mediante la perspectiva del procesamiento ortográfico y el intervalo de atención visual. Estudiamos el procesamiento ortográfico mediante una tarea en la que los participantes debían detectar letras que aparecían en pseudopalabras que no contenían ningún morfema real o que contenían una raíz o un sufijo. Los niños de cuarto curso que realizaron las tareas presentadas en el estudio anterior también participaron en este.

El descubrimiento clave de este estudio es que la presencia de raíces y sufijos afecta a la distribución de la atención visual de los lectores avanzados respecto a las pseudopalabras. Esto sugiere que, mientras los lectores desarrollan sus capacidades, puede que su conocimiento morfológico condicione sus estrategias atencionales y su rendimiento lector. En mayor medida, el patrón que se observó para las raíces (la atención visual se enfoca en la raíz y no en el resto de la pseudopalabra) podría explicar la ausencia del efecto del intervalo de atención visual en la lectura cuando se leen estímulos complejos (estudio anterior). Si la raíz funciona como un grano ortográfico grande que destaca y ocupa recursos atencionales a niveles más altos de procesamiento cognitivo, podría interferir en la asignación de estos recursos al procesamiento lexico-ortográfico. Por otro lado, el sufijo (cuya presencia desplaza la atención hacía el resto de la pseudopalabra, es decir, la parte de la raíz, ya que es fácil de procesar) podría disminuir los requisitos sobre la atención visual y, en vez de interferir con el procesamiento ortográfico, acelerarlo.

Conclusión general

La presente tesis tenía como objetivo investigar la modulación del tamaño del grano ortográfico (usando como medida principal el intervalo de atención visual) en relación con tres factores principales: la consistencia/complejidad ortográfica, la complejidad y estructura morfológica y la experiencia lectora. Los resultados indican que todos estos factores influyen el tamaño del grano ortográfico.

Consideramos que la experiencia y la fluidez lectora pueden determinar si se puede observar la influencia de los otros factores. Más concretamente, debido a que los lectores tempranos solo pueden procesar unidades ortográficas pequeñas, es difícil observar la modulación de su tamaño como resultado de otros factores. Después de adquirir cierta fluidez lectora, se puede observar que una mayor complejidad/inconsistencia ortográfica se relaciona con el uso de mayores granos ortográficos y demandas más altas en cuanto al intervalo de atención visual. Finalmente, la complejidad morfológica también afecta a la disponibilidad de granos ortográficos mayores, ya que la presencia de morfemas subléxicos reduce las demandas visuoatencionales; un efecto que consideramos que proviene principalmente de la presencia de las raíces.

Los resultados de la presente tesis, pese a sus limitaciones, son relevantes para los estudios futuros sobre el desarrollo de la lectura, especialmente en relación a la adquisición de representaciones ortográficas de las palabras y la subsiguiente habilidad para leer mediante la vía léxica y procesar unidades ortográficas de mayor tamaño. Nuestros estudios han destacado que el grano ortográfico se modula por la experiencia/fluidez lectora, la consistencia/complejidad ortográfica y su interacción. A su vez, han demostrado el efecto de la complejidad morfológica en la lectura y el papel del intervalo de atención visual. El estudio de estos factores a través de la nueva perspectiva de la modulación del grano ortográfico (Grainger & Ziegler, 2011; Lallier & Carreiras, 2018) ofrece otra vía para investigar las exigencias y limitaciones impuestas por el procesamiento ortográfico a la atención visual del lector. En el futuro, los estudios podrían describir en más profundidad las interacciones entre estos factores.

Related publications and manuscripts

Antzaka, A., Acha, J., Carreiras, M., Lallier, M. (under review). The deployment of young readers visual attention across orthographic strings: the influence of stems and suffixes.

Antzaka, A., Acha, J., Carreiras, M., Lallier, M. (accepted). Does the visual attention span play a role in the morphological processing of orthographic stimuli? *The Quarterly Journal of Experimental Psychology*.

Antzaka, A., Martin, C., Caffarra, S., Schlöffel, S., Carreiras, M., Lallier, M. (2018). The effect of orthographic depth on letter string processing: The case of visual attention span and rapid automatized naming. *Reading and Writing*, *31*, 583-605. doi: 10.1007/s11145-017-9799-0

Awadh, F. H. R., Phénix, T., Antzaka, A., Lallier, M., Carreiras, M., Valdois, S. (2016). Cross-language modulation of visual attention span: An Arabic-French-Spanish comparison in adult skilled readers. *Frontiers in Psychology*, *7*:307. doi: 10.3389/fpsyg.2016.00307

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Appendix A

A.1 Basque text adapted from the book: "Printze txikia"

Laster ikasi nuen lore hori hobeto ezagutzen.

Printze txikiaren planetan beti egon izan omen ziren lore xumeak,

lore-hosto hilar bakar batekin apaindurik, ia lekurik betetzen ez zutenak, eta

inorentzat desatsegin edo deigarri ez zirenak.

Goiz batean agertzen ziren belar artean eta arratsaldean hil egiten ziren.

Baina lore hau egun batean sortu zen leku ezezagunetik etorritako hazi batetik,

eta printze txikiak gertutik zaindu izan zuen izpi hura, eta ez zuen inolako antzekotasunik beste izpiekin. Hau baobab mota bat izan zitekeen. Baina zuhaixkak, bapatean, hazitzeari utzi zion eta lore bat sortu zen.

A.2 Spanish text adapted from the book: "El Principito"

Pronto aprendí a conocer mejor esa flor.

En el planeta del principito siempre había habido flores muy sencillas,

adornadas con una sola hilera de pétalos, que casi no ocupaban espacio y que a nadie molestaban ni llamaban la atención.

Aparecían una mañana entre la hierba y morían por la tarde.

Pero aquélla había germinado un día de una semilla venida de algún lugar desconocido y el principito había cuidado muy de cerca a esa brizna y no tenía ninguna semejanza a las otras briznas. Esta podía ser un nuevo género de baobab. Pero el arbusto, de pronto, dejó de crecer y brotó una flor.

A.3 French text from the book: "Le Petit Prince"

J'appris bien vite à mieux connaître cette fleur.

Il y avait toujours eu, sur la planète du petit prince, des fleurs très simples,

ornées d'un seul rang de pétales, et qui ne tenaient point de place, et qui

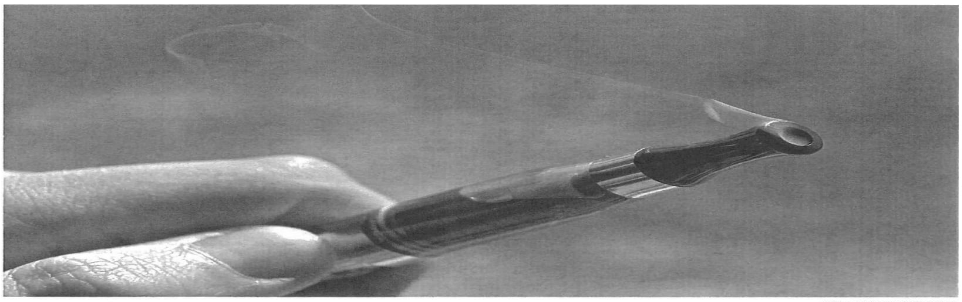
ne dérangaient personne. Elles apparaissaient un matin dans l'herbe, et puis elles s'éteignaient le soir.

Mais celle-là avait germé un jour, d'une graine apportée d'on ne sait où,

et le petit prince avait surveillé de très près cette brindille qui ne ressemblait pas aux autres brindilles. ça pouvait être un nouveau genre de baobab. Mais larbuste cessa vite de croître, et commença de préparer une fleur.

Appendix B

B.1 Basque newspaper text for adults



Zigarro elektronikoa zalantzak lurrun artean

ANA GALARRAGA AIESTARAN *Elhuyar Zientzia*

Zigarro elektronikoarekin, tabakoa kontsumitzeko beste modu bat azaldu da, eta kontsumo-mota horrek izan ditzakeen eraginak ikertzen ari dira orain, neurri eta arau egokiak ezarri ahal izateko. Oraindik, ordea, goizegi da ebidentzia zientifikoetan oinarritutako ondorioak ateratzeko, eta, bitartean, eztabaida puripurian dago.

¨Ez dakigu, baina, behintzat, badakigu ez dakigula¨. Francisco Javier Ayestaren aitortza da. Ayesta farmakologia-irakaslea da Kantabriako Unibersitatean, eta tabakismoan aditua. Zigarro elektronikoari buruz Deustuko Unibersitateak antolatutako jardunaldian esan zituen hitz horiek, eta gainerako adituak ados ziren harekin.

Azkenaldian ikertzaileak eta profesionalak egiten ari diren jardunaldietako bat izan zen Deustukoa. Zigarro elektronikoa arazo ala irtenbide ote den aztertzeko, Ayestarekin batera, Kataluniako Generalitateko eta Gasteizko udaleko osasun publikoko adituak (Esteve Saltó eta Joseba Zabala), Kataluniako Onkologia Institutuko epidemiologo bat (Esteve Fernández) eta Galdakaoko ospitaleko Tabakismo Unitateko arduraduna (Juana Umaran) bildu ziren.

Hasieratik onartu zuten galdera gehiago zituztela erantzunak baino. Izan ere, ikerketa gutxi egin dira orain arte zigarro elektronikoaren eraginei buruz, eta horietako askok akats metodologikoak dituzte. Gogorarazi zutenez, produktu berria eta oso heterogeneoa da, eta horrek asko zailtzen du ikerketa onak egitea, ebidentzietara iristea eta ondorio sendoak ateratzea.

Oinarrian, antzeko funtzionamendua dute zigarro elektroniko guztiek. Erresistentzia eta bateria baten bidez, nikotina duen likido bat berotu eta lurruntzen dute, eta lurrun hori da kontsumitzaileak inhalatzen duena. Hon Lik farmazialari txinatarrak patentatu zuen sistema hori 2003an, eta, Europako merkatuan sartzeko denbora pixka bat behar izan bazuen ere, azken urteetan azkar hedatu da. Hala 2012an 500 milioi euroko irabaziak lortu zituzten zigarro elektronikoen saltzaileek.

Jakina, arrakasta horretan eragin handia izan du tabako-industriaren ahaleginak. Izan ere, harentzat aukera paregabea da tabakoaren neurriak zorroztearen ondorioz galdutako merkatua berreskuratzeko. Horregatik, lehenik, tabako-konpainiak zigarro elektronikoak ekoizten hasi dira, edo ekoizleak bereganatu dituzte, eta, gero, publitzitatea egitean, indar berezia jarri dute ohiko zigarroaren ordezko osasungarri gisa agerrarazten.

Bestelakoan, saltzeko erabiltzen dituzten estrategiak eta ikonografia duela 50 urte erabiltzen zituzten berberak dira: zigarro elektroniko kontsumitzeak gizonezkoen gizontasuna (gizonkeria) nabarmentzen du, emakumezkoei glamourra ematen die, eta gazteak heldu bihurtzen ditu.

Berez, osasungintza-arlokoak ez lirateke zigarro elektronikoa hain erakargarria izateagatik kezkatu behar, ez balu inolako ondorio txarrik osasunean. Alabaina, Osasunaren Mundu Erakundeak berak 2013ko uztailean ohartarazi zuenez, ¨nikotina emateko gailu elektronikoen segurtasuna ez dago zientifikoki frogatuta. Erabiltzaileen osasunean izan ditzaketen arriskua zehaztu gabe dago oraindik. Are gehiago, proba zientifikoek erakutsi dute produktua oso aldakorra dela ematen duen nikotinaren eta beste gai kimikoen kantitatean, eta kontsumitzaileek ez dutela aukerarik jakiteko zehazki zer ematen duen erosi duen produktuak¨.

ERAGINAK AZTERTZEN

Deustuko jardunaldian parte hartu zuten adituak bat zetozen OMEren jarrerarekin. Haien ustez, ebidentzia sendoak izan arte, funtsezkoa da zuhurtzia-printzipioari eustea. Baina harago joan ziren, eta hainbat galdera eta zalantza plazaratu zituzten. Adibidez, egia bada erretzeak baino kalte gutxiago egiten duela inhalatzeak, zigarro elektronikoa izan daiteke aukera ona tabakoa uzten laguntzeko, edo tabako-erretzaile borrokatuei ordezko ez hain kaltegarria eskaintzeko?

Gai horrek eztabaida handia sortzen du, oraindik ez dagoelako garbi zenbateraino den zigarro elektronikoa ohikoa baino hobea osasunerako. Ayestak gogorarazi zuen edozein substantziaren eragina hartzeko bidearen araberakoa dela. Horren adibidetzat jarri zituen koka-infusioa, kokaina klorhidratoa eta craka; lehena edan egiten da, bigarrena esnifatu, eta hirugarrena da gogorrena, eragin azkarrena eta handiena duena.

Tabakoaren kasuan, ohiko zigarroekin, eraginkorrena inhalatutako kea dela esan zuen Ayestak; eta eragina askoz ere apalagoa dela ez bada inhalatzen. Tabakoa hartzeko beste sistemetatik, berriz, spraya da gogorrena (erretzean kea inhalatzearen parekoa), eta txaplatak arinenak. Bada, Ayestaren esanean, zigarro elektronikoaren eragina sprayaren parekoa da.

Hala ere, Ayestak gogora ekarri zuen zigarro elektronikoek duten likidoaren konposizioa asko aldatzen dela batetik bestera, nahiz eta, nikotina-kontzentrazioan, behintzat badagoen arau bat. Hain justu, Europako Batasunak gehienezko nikotina-kontzentrazioa 20mg/ml-ko muga ezarri du duela gutxi. Ayestak, dena den, jakinarazi zuen kontzentrazio hori nahikoa zela mendekotasuna eta nikotinaren beste ondorioak eragiteko.

Sendagileak gehien kezkatzen dituena arrisku kardiobaskularra da. Izan ere, bihotzekoa izateko arrisku-faktore nagusia hipertensioa da, eta haren atzetik dator tabakoa erretzea. Gainera, arriskua ez da areagotzen dosiarekin batera: egunean zigarro bakarra erreta ere, 20 urtez errez gero, arrisku kardiobaskularra % 30 areagotzen da. Orain arteko datuetan oinarrituta, zigarro elektronikoek ohikoek baino arrisku txikiagoa sortzen dutela iritzi dio Ayestak, ¨gutxi gorabehera, haiek sortzen dutenaren erdia¨, zehastu zuen.

Ohiko zigarroaren beste ondorio batzuk, baina, ez daude nikotinari lotuta. Eta horietan badago aldea zigarro elektronikoarekiko. Horri esker, zigarro elektronikoaren toxikotasuna ohikoarena baino dezente txikiagoa da. Ayestak ñabardura bat gehitu zuen, hala ere: ¨Kontuz ibili behar dugu horrelakoak esatean, ezin baitugu ziur baieztatu. Baina zaila da zigarro elektronikoa ohikoa baino toxikoagoa izatea, hura oso baita toxikoa¨.

Esaterako, biriketako minbizia izateko arriskua areagotzen duten substantzia asko ditu ohiko zigarroak, eta badirudi zigarro elektronikoek erabiltzen duten likidoan ez daudela hainbeste substantzia kartzinogeno, edo ez behintzat aintzat hartzeko kantitatetan, denek baitituzte nitrosaminak eta propilenglikola, baina oso kontzentrazio txikietan.

Aldiz, likidoek gehigarri pila bat izaten dituzte, 600 baino gehiago oro har. Gehigarri horiek elikagai-industrian erabiltzen dira, eta jateko seguruak dira; alabaina, ez dago frogatuta ez dutela kalterik sortzen berotu eta inhalatzen direnean. Alderdi horretan ere, berriro etorri ziren bat guztiak:¨Ikerketa gehiago egin behar dira¨.

Figure B.1: Basque text adapted from the newspaper: “Elhuyar”

Appendix C

C.1 Morphological naming task stimuli and descriptive statistics

Table C.1: Stimuli used in the naming task on morphological processing

Lexicality	Morphological complexity	Word frequency[a]	Stem frequency[a]	Item
Word				
	Complex	high	high	euskaldun
				elkarte
				orokor
				aldizkari
				emaitza
				langile
				ondorengo
				ariketa
				jardun
				egunkari
			low	artzain
				aldaketa
				azterketa
				batzar
				aukera
				ordezkari
				margolari
				irabazle
				lorategi
				iraultza
		low	high	behitegi
				osagile
				elurte
				saridun
				bereizle
				berekoi
				asmakari
				beldurti

Continued on next page

Table C.1 – continued from previous page

Lexicality	Morphological complexity	Word frequency	Stem frequency	Item
				iheskor
				zezenketa
			low	iratxo
				kexati
				lohitsu
				nagikeria
				erkaketa
				titidun
				muntaketa
				segalari
				dirdaitsu
				eltzekari
	Simple	high		ezaugarri
				alargun
				aurpegi
				harreman
				borroka
				ondorio
				istripu
				zuhaitz
				tximeleta
				argazki
				panpina
				bilduma
				baserri
				korapilo
				adiskide
				arrakasta
				eskaini
				erantzun
				otoitz
				zerrenda
		low		ukuilu
				legamia
				berakatz
				lursail
				guraize
				kriseilu
				olagarro
				goroldio
				izpiliku
				txintxeta
				erdeinu
				zingira
				adaxka
				torloju
				zikoina

Continued on next page

Table C.1 – continued from previous page

Lexicality	Morphological complexity	Word frequency	Stem frequency	Item
				baraila
				inauteri
				zintzarri
				gerruntze
				mitxoleta
Pseudoword[b]				
	Complex			**euskal**tin
				entan**te**
				orotek
				anbal**kari**
				igo**itza**
				mes**gile**
				ontokil**go**
				arigiro
				jarten
				egungaku
				ent**zain**
				aldamiro
				exkar**keta**
				batzon
				autika
				ordeztaku
				hesfo**lari**
				ilaho**sle**
				biti**tegi**
				iraultxe
				behilezu
				osazigu
				ekis**te**
				sarizar
				bereizdi
				bili**koi**
				imne**kari**
				bezkor**ti**
				ihestal
				demal**keta**
				irarra
				mima**ti**
				lohiklo
				zita**keria**
				erkaliro
				nebi**dun**
				horda**keta**
				segazare
				dunka**itsu**
				eltzerake

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Table C.1 – continued from previous page

Lexicality	Morphological complexity	Word frequency	Stem frequency	Item
	Simple			ataugatze
				alanken
				ainpesi
				harripen
				lerrota
				osnorea
				inflixu
				muzaitz
				tribizeta
				alzizki
				zarkina
				bardoma
				bafeklo
				dirafino
				amaktide
				arratenra
				eldeuni
				eroltxun
				asoitz
				zerrurga
				uduizi
				sahadia
				biraritz
				gurlail
				kurauzi
				frinaulu
				oxibarra
				gorepzio
				ispareku
				txartzeta
				erdeuli
				zirbika
				aziska
				targoxu
				likeila
				bagoina
				otaurere
				zaltsarri
				zerrontzi
				botxuseta

[a] Items are marked as high or low frequency depending on whether Zipf frequency was above or below 4 respectively (Van Heuven, Mandera, Keuleers, & Brysbaert, 2014). [b]The real morpheme is presented in boldface.

Table C.2: Descriptive statistics of the variables used to match the naming task stimuli on our main conditions of interest

Lexicality	Morphological complexity		Length	Average bigram token frequency	Zipf word frequency	Zipf stem frequency
Pseudowords						
	Simple (N=40)	*M(SD)*	7.55 (0.88)	226 (134)		
		Range	6 - 9	32 – 701		
	Complex (N=40)	*M(SD)*	7.65 (1.08)	230 (209)		
		Range	6 - 9	30 – 1291		
Words						
	Simple (N=40)	*M(SD)*	7.55 (0.88)	243 (142)	3.94 (0.94)	
		Range	6 - 9	35 – 591	2.54 – 5.78	
	Complex (N=40)	*M(SD)*	7.65 (1.08)	239 (114)	3.93 (0.97)	4.52 (1.10)
		Range	6 - 9	53 – 579	1.95 – 5.80	2.49 – 6.67
Comparisons						
			ps>.60	*ps*>.11	*p*>.96	

Note. Wilcoxon signed rank tests were used for the comparisons. Measures used only for words were taken from the EHME database (Acha et al., 2014). Measures that were needed for both words and pseudowords were taken from E-HITZ (Perea et al., 2006).

Table C.3: Descriptive statistics on the word and stem frequencies of the word subsets that we investigated in our additional analyses

Frequency		**Length**[a]	**Average bigram token frequency**		**Zipf word frequency**		**Zipf stem frequency**	
Word	**Stem**	Mean *(SD)*	Mean *(SD)*	Range	Mean *(SD)*	Range	Mean *(SD)*	Range
Simple words								
High		7.5 (0.83)	274 (141)	122 - 591	4.8 (0.47)	4.01 – 5.78		
Low		7.6 (0.94)	213 (141)	35 – 562	3.09 (0.25)	2.54 - 3.48		
Complex words								
High	High	7.5 (1.18)	203 (71)	113 – 371	4.84 (0.29)	4.44 – 5.22	5.87 (0.37)	5.22 - 6.36
	Low	7.8 (1.14)	302 (138)	160 - 579	4.77 (0.54)	4.06 - 5.80	3.55 (0.71)	2.49 – 4.30
Low	High	7.5 (0.85)	243 (139)	53 – 529	3.04 (0.43)	2.41 – 3.66	4.91 (0.75)	4.13 - 6.67
	Low	7.8 (1.23)	206 (77)	108 - 353	3.08 (0.44)	1.95- 3.44	3.75 (0.31)	3.06 – 4.00

[a] Length ranged from six to nine letters in all conditions.

Appendix D

D.1 Morphological one-back task stimuli and accuracy scores

Table D.1: Stimuli used in the letter detection visual one-back task

Condition	Trial Type	Sub-condition	Target	Pseudoword
Morphologically Complex				
	Present	+stem-suffix	A	AHOIDER
			A	ATEOSDU
			A	AHOILUS
			A	ATEOZPU
			A	IGOARFU
			A	OINAKRE
			A	IGOABLU
			A	OINAPLE
			A	IGOFEMA
			A	OINUSTA
			A	IGOLDUA
			A	OINRUXA
			I	IGOSKEN
			I	ILEOFUZ
			I	IGORTEZ
			I	ILEOSKU
			I	OHEIPZU
			I	AHOILER
			I	OHEIZFU
			I	AHOIKEL
			I	OHERTAI
			I	AHOMEFI
			I	OHEGUZI
			I	AHOGELI
			O	OINARLE
			O	OHEIFUN
			O	OINAMRU
			O	OHEIDUZ
			O	ILEOSNU

Continued on next page

Table D.1 – continued from previous page

Condition	Trial Type	Sub-condition	Target	Pseudoword
			O	ATEOMUN
			O	ILEONDU
			O	ATEORUF
			O	ILEAGNO
			O	ATEMUDO
			O	ILEATRO
			O	ATEKUBO
		-stem+suffix	A	ADEZKOI
			A	ARTUKOI
			A	AMLITXO
			A	ABNITXO
			A	UZFAKOI
			A	BENAKOI
			A	ZUKATXO
			A	URDATXO
			A	TSUNERA
			A	PEMOTZA
			A	GULMERA
			A	BRUOTZA
			I	IMDEARO
			I	IGUXARO
			I	ISTOERA
			I	IZKOERA
			I	GUDIARO
			I	FULIARO
			I	UXTIERA
			I	GUPIERA
			I	PERAKOI
			I	STRUGAI
			I	ERTAKOI
			I	EZDUGAI
			O	OLPEGAI
			O	OFENGAI
			O	OKLITZA
			O	OSRITZA
			O	URFOGAI
			O	ELMOGAI
			O	URGOTZA
			O	EKPOTZA
			O	UZENARO
			O	ERMATXO
			O	UKENARO
			O	ULFATXO
	Absent	+stem-suffix	A	IGONEZU
			A	OINTZUK
			A	IGOREMU
			A	OINESPU
			A	IGOSPRU

Continued on next page

Table D.1 – continued from previous page

Condition	Trial Type	Sub-condition	Target	Pseudoword
			A	OINUTEL
			I	AHOSDUM
			I	OHEALZU
			I	AHODUTZ
			I	OHEASFU
			I	AHOGUDE
			I	OHEAFLU
			O	ATEIZKU
			O	ILEASMU
			O	ATEIRMU
			O	ILEATRU
			O	ATEIZDU
			O	IGEATXU*
		-stem+suffix	A	UGNEKOI
			A	GEFUKOI
			A	TZENKOI
			A	USNETXO
			A	BUERTXO
			A	ULGITXO
			I	EZPUARO
			I	UXEDARO
			I	FETKARO
			I	ULNOERA
			I	GLUOERA
			I	LUPOERA
			O	URKEGAI
			O	URENGAI
			O	ZUDEGAI
			O	URPETZA
			O	ELSITZA
			O	EFRITZA
Morphologically Simple				
	Present		A	AZMIERU
			A	AGUISON
			A	AKEIZGU
			A	ATSOELU
			A	ATXODEI
			A	ARUKEXI
			A	AHELUZO
			A	ARENUXO
			A	ILKASFE
			A	ISUARON
			A	OGDAINE
			A	ONEARUZ
			A	EMOATSI
			A	GEOARXI
			A	ULEARGO
			A	ENBATLO

Continued on next page

Table D.1 – continued from previous page

Condition	Trial Type	Sub-condition	Target	Pseudoword
			A	IBOGURA
			A	IRDUNEA
			A	OLKURZA
			A	OIPUXKA
			A	PUFIEKA
			A	UZGITSA
			A	FIDOGNA
			A	UTXOSRA
			I	IRLOMTU
			I	IKTOLMU
			I	IPSALDU
			I	IFRATUN
			I	ITENAKO
			I	ILUZAXO
			I	IRNETUA
			I	IHESLUA
			I	OGNIAZU
			I	ORLIENU
			I	ALEIKZU
			I	ARZINUK
			I	ULTIZRO
			I	BUNIFTO
			I	PEGINOA
			I	TUHIMOA
			I	OSTEFRI
			I	OGERADI
			I	AGOSEMI
			I	AXETUNI
			I	ENDOALI
			I	ZENOAGI
			I	UKOAGDI
			I	UHEALTI
			O	ORGIKUN
			O	OHLIGAZ
			O	ODUALTE
			O	OLEASRI
			O	OTESURI
			O	OPELATI
			O	OTUNKEA
			O	OIZENBA
			O	ILDOASE
			O	ISKOEGU
			O	ALFOKER
			O	ASLOTZU
			O	BINOZLE
			O	UNDOERI
			O	UTSODIA
			O	ENTOILA

Continued on next page

Table D.1 – continued from previous page

Condition	Trial Type	Sub-condition	Target	Pseudoword
			O	IHUNEDO
			O	ILTUAMO
			O	AZEDUFO
			O	AMUENDO
			O	PIDUTAO
			O	ULPIZAO
			O	GINATEO
			O	USPAMLO
	Absent		A	BITEZON
			A	UZTIFEN
			A	BIMEOLU
			A	USTEODI
			A	IFENUTO
			A	ISEDOKU
			A	OLIUREN
			A	OLDIFER
			A	PUKOREI
			A	BOSUNEI
			A	IGRUSTO
			A	IRETUNO
			I	UNAORDE
			I	EDRONAU
			I	USKERAO
			I	PURATZO
			I	ORUTAGE
			I	OFUZAME
			I	APTOLEN
			I	AMNOEKU
			I	URLANTO
			I	GETORAU
			I	OFRUSEA
			I	OBEFUGA
			O	AHRISTU
			O	AGNIDRE
			O	TURAZNI
			O	URMANTI
			O	IKRUEPA
			O	URBEIMA
			O	ABRIMEN
			O	AFEIGRU
			O	ESMAIZU
			O	EHUAZBI
			O	EZBUNIA
			O	ITXELKA

* The stimulus that was removed from the analysis due to the incorrect substitution of the stem “*ile*” by “*ige*”.

Table D.2: Descriptive statistics on accuracy scores on morphological visual one-back task

Pseudoword condition and sub-condition		**Percent (%) correctly identified letters by position and on absent trials*** Absent	**1**	**4**	**7**
Morphologically Simple					
-stem -suffix	Mean *(SD)*	70 (20)	78 (17)	73 (19)	64 (23)
	Median	72	79	75	69
	Range	25 – 94	42 – 100	8 – 96	12 – 96
Morphologically Complex					
All items	Mean *(SD)*	69 (19)	80 (12)	73 (20)	66 (20)
	Median	71	83	81	73
	Range	29 – 94	52 – 100	25 – 96	21– 96
+ stem -suffix	Mean *(SD)*	71 (18)	80 (15)	70 (23)	67 (23)
	Median	76	83	75	75
	Range	24 – 100	42 – 100	17 – 92	17 – 100
- stem +suffix	Mean *(SD)*	67 (22)	80 (13)	77 (22)	66 (22)
	Median	67	83	83	71
	Range	28 – 100	50 – 100	25 – 100	17 – 100

Note. SD: standard deviation. * In our case children had 67% probability of being accurate responding positively. Nevertheless, it has been suggested that the higher the probability of giving a specific type of answer, the more likely people are to underestimate the chance level (Lee & Danileiko, 2014).

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