Bilingualism: Language and Cognition

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Research Article

Cite this article: Venagli, I., Kupisch, T. and Lallier, M. (2025). How English orthographic proficiency modulates visual attention span in Italian learners with and without dyslexia. *Bilingualism: Language and Cognition* 1–14. https://doi.org/10.1017/S1366728925000124

Received: 31 May 2024
Revised: 09 January 2025
Accepted: 13 January 2025

Keywords:
visual attention span; developmental dyslexia; grain size accommodation hypothesis; second language acquisition; biliteracy

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This research article was awarded Open Data and Open Materials badges for transparent practices. See the Data Availability Statement for details.

How English orthographic proficiency modulates visual attention span in Italian learners with and without dyslexia

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Abstract

Visual attention span (VAS) refers to the number of visual elements processed simultaneously in a multielement array. It is causally related to reading skills and may be impaired in readers with dyslexia. VAS is influenced by orthographic depth with opaque orthographies boosting it. Such orthography-specific VAS modulations are subject to crosslinguistic interactions in early biliterates, leading to advantages associated with learning to read in an opaque orthography. However, little is known about potential VAS bootstrapping effects in late biliterates. This study investigates potential VAS modulation in late biliterates with and without dyslexia. Participants were first language (L1) Italian native speakers (transparent orthography) learning English as a second language (L2). Our results show that the VAS capacity of typical readers is modulated by English orthographic knowledge, providing the first evidence that experience with a nonnative orthography boosts VAS skills also in late biliterates. This effect was reduced in dyslexic learners, possibly due to a VAS deficit.

Highlights

- Biliteracy affects cognitive attentional priors for multielement array processing.
- Acquiring an opaque second language (L2) modulates visuospatial sensitivity.
- Learning an opaque L2 boosts visual attention span (VAS) skills in late L2 learners.
- Orthography-specific VAS modulation may be reduced in the presence of dyslexia.

1. Introduction

Reading development entails learning how written symbols encode speech sounds. However, the integration of visual information into speech varies across languages, which implies that reading strategies and reading-related cognitive skills develop in tune with language-specific orthographic properties. Reading in alphabetic orthographies primarily involves mapping graphemes onto phonemes (Ziegler & Goswami, 2005) and therefore strongly relies on phonological and especially phonemic processing skills. However, the complexity of grapheme-to-phoneme correspondences (GPCs) varies across languages that involve phonological mapping (Borleffs et al., 2017; Katz & Frost, 1992; Schmalz et al., 2015). This is reflected in various ways: (i) Across languages, speakers employ different strategies to map orthography to phonology (Marinelli et al., 2016; Ziegler & Goswami, 2005; Ziegler et al., 2001), (ii) children develop reading skills at different speeds (Seymour et al., 2003) and (iii) the manifestation and severity of reading impairments, such as developmental dyslexia, vary (Lallier et al., 2018b; Ziegler & Goswami, 2005).

Differences in grapheme-to-phoneme mappings have traditionally been couched in terms of SHALLOW/TRANSPARENT versus DEEP/OPAQUE orthographies[1] (Borleffs et al., 2017; Schmalz et al., 2015). In languages with more transparent orthographies (e.g., Italian, Spanish or Finnish), GPCs are almost 1:1, with few exceptions. For instance, the Italian vowel <a > in *gatto* "cat" or *torta* "cake" is always pronounced [a], regardless of positional and lexical constraints.[2] The consistency of GPCs leads readers of transparent orthographies to heavily rely on phonological processing skills, which enhances the sublexical reading pathway (Ziegler & Goswami, 2005). In more opaque orthographies, by contrast, GPCs are less consistent and less predictable. In English, phonological recoding relies heavily on the processing of large multi-letter orthographic chunks,

[1]The categorization of orthographies into SHALLOW/TRANSPARENT and DEEP/OPAQUE based on grapheme-to-phoneme mapping is seen as a continuum.

[2]Exceptions concern the consonants <c > and < g>, which are pronounced [k] and [g] before <a>, <u> and < o> and [ʧ] and [dʒ] before the vowels <i > and < e>.

that is, <int> in *pint* will be pronounced [aɪnt] but [ɪnt] in *mint*, reflecting that GPC rules are strongly affected by positional and lexical constraints (Perfetti & Harris, 2019). Thus, reading opaque orthographies triggers strategies that boost the lexical reading route (Perfetti & Harris, 2019, p. 29; Ziegler & Goswami, 2005), which entails processing words as wholes to retrieve their representations from memory (Coltheart, 2005; Coltheart et al., 2001).

Given that many people today are multi-literate, there has been a growing interest in understanding how bilingual experience influences the cognitive and neural networks that are involved in reading and how being literate in multiple languages can impact reading strategies. Lallier and Carreiras (2018) proposed that learning two orthographies with different depths may affect reading skills and subskills through crosslinguistic transfer. However, this hypothesis has so far only been tested in early bilinguals with comparatively balanced proficiency and reading experience in their two native languages. Reading abilities in late bilinguals, who acquire a second language (L2) only at school (henceforth "late biliterates"), have not been a prominent research topic so far. The present study aims to investigate whether Lallier and Carreiras' (2018) hypothesis on crosslinguistic transfer in reading also extends to late biliterates with and without developmental dyslexia.

2. Background

2.1. Cognitive underpinnings of reading development and developmental dyslexia

While it is still under debate whether the development of reading skills is guided by universal principles, it is generally assumed that children undergo two developmental phases when acquiring reading skills: In the first phase, they learn how written symbols encode speech sounds; in the second phase, they develop abstract orthographic representations of words. The latter will facilitate immediate word recognition during reading. These two phases underpin the development of two distinct reading procedures: a sublexical (or analytical) procedure and a lexical (or global) procedure (Ans et al., 1998; Coltheart, 2005; Coltheart et al., 2001). Sublexical reading strategies are developed early and involve a costly computational process whereby each sublexical graphemic unit is converted into its corresponding sound. By contrast, lexical reading strategies involve accessing the representation of words in the mental lexicon.

Since reading research has primarily focused on alphabetic orthographies, which rely on grapheme-to-phoneme mapping, auditory phonological skills were traditionally considered to be the most important precursors of reading skills (Ziegler et al., 2010; Ziegler & Goswami, 2005). Auditory phonology skills include phonological awareness (i.e., the ability to access, analyze and manipulate speech sounds), phonological short-term/working memory, phonological access and fluency. The prominent role of phonological skills in reading development has also been supported by studies on developmental dyslexia (Ramus et al., 2003; Snowling, 2001; Vellutino et al., 2004), a learning disorder that is associated with persistent poor word recognition and decoding skills. Beyond phonological processing abilities, visual–attentional skills also contribute to reading development. These ensure the efficient allocation of visual resources on letter strings during reading (Gavril et al., 2021), and they are crucial for efficient graphemic parsing (Grainger et al., 2016) and whole word recognition (Bosse et al., 2015; Lallier et al., 2018b). Of particular interest here is the visual attention span (VAS hereafter), that is, the number of visual elements that can be processed simultaneously within a single fixation. VAS is especially important for the development of an orthographic lexicon and reading through the lexical route (Bosse, 2015; Bosse et al., 2007; Valdois, 2022). Interestingly, VAS abilities strongly contribute to reading and dyslexia not only in alphabetic orthographies with inconsistent GPCs (Bosse et al., 2007; Bosse & Valdois, 2009; Lallier et al., 2013b, 2013c; Lobier et al., 2012, 2013; Valdois et al., 2004, 2019) but also in more consistent orthographies (Germano et al., 2014; Lallier et al., 2021; van den Boer et al., 2015), as well as vowelized (e.g., Arabic; Awadh et al., 2022) and logographic (e.g., Chinese; Huang et al., 2019) orthographies.

As for dyslexia, multifactorial models suggest that it may stem from deficits at various levels involved in the reading process (e.g., Bosse et al., 2007; Lorusso & Toraldo, 2023; Perry et al., 2019; Ziegler et al., 2020). While phonological deficits (e.g., phonological awareness, phonological short-term/working memory, rapid automatized naming [RAN]) have been extensively discussed, growing evidence suggests that visual-processing deficits, such as VAS impairments, can also explain some forms of dyslexia. VAS deficits result in impaired and slower parallel processing of multielement arrays (Valdois, 2022) and can hinder lexical reading abilities. Moreover, crowding effects, that is, inaccurate letter recognition due to neighboring letters, have also been linked to decoding difficulties in dyslexia (e.g., Martelli et al., 2009; Spinelli et al., 2002, for Italian). Crowding effects and VAS are inversely related, with increased crowding reducing the ability to process multiple letters simultaneously. Accordingly, reliance on sublexical reading strategies may reduce vulnerability to crowding effects (Lallier et al., 2018a).

2.2. Effects of orthographic depth and biliteracy on VAS

VAS has been conceptualized as a window of visual simultaneous attention, which can vary in size (Ans et al., 1998). Efficient sublexical reading requires a narrow attentional focus on each sublexical unit within an orthographic string to facilitate phonological decoding. Conversely, learning to read through the lexical pathway requires attentional resources to be distributed more broadly and homogeneously across entire words to facilitate the formation of their lexical representations allowing their direct retrieval from memory.

Since the way letters are mapped to sounds varies across languages, reading skills and subskills (including VAS) may be modulated by orthography-specific properties. As previously discussed, studies have shown that readers of transparent orthographies rely more heavily on sublexical, small-grain reading strategies, while readers of more opaque orthographies rely more on larger-grain-size strategies (Lallier & Carreiras, 2018; Ziegler & Goswami, 2005). Even early bilinguals with literacy in both an opaque orthography and a transparent orthography engage different strategies depending on the language in which they read (Buetler et al., 2014; de León Rodríguez et al., 2016; Egan et al., 2019; Iniesta et al., 2023; Lallier et al., 2014; Lallier & Carreiras, 2018). These crosslinguistic differences support the psycholinguistic grain size theory (Ziegler & Goswami, 2005) that posits that the size of the phonological units that one relies on when learning to read is inversely proportional to GPC consistency and predictability, that is, opaque orthographies trigger the reliance on larger phonological grain size units than transparent orthographies. Building on this, Lallier and Carreiras (2018) propose that these modulations could also affect the visual orthographic grain of processing and the underlying VAS. For instance, to correctly pronounce the irregular word *queue* in English, visual attention needs to be homogeneously distributed across

https://doi.org/10.1017/S1366728925000124 Published online by Cambridge University Press

all the five letters in the word. Conversely, in Italian, the word *coda* "queue" can be accurately decoded through a narrow visual attention focus on individual letters to access the correct corresponding sounds. This goes in line with evidence suggesting that Italian and English differ with respect to the maximum size of the visual–attentional "window" required for reading (Perry & Long, 2022, p. 6) and that VAS skills contribute more strongly to reading in opaque orthographies (Awadh et al., 2016; Gavril et al., 2021).[3]

While most of the evidence supporting the psycholinguistic grain size theory comes from monolingual readers, biliterate experience and crosslinguistic transfer can also shape reading strategies in specific ways (Lallier & Carreiras, 2018). For example, early biliteracy modulates the preferred grain size of reading strategies (Lallier et al., 2016, 2018b) and reading subskills, including VAS and phonological abilities (Antzaka et al., 2018; Lallier et al., 2014, 2016; Lallier & Carreiras, 2018). To explain these effects, Lallier and Carreiras (2018) proposed the grain size accommodation hypothesis, according to which the acquisition of two different writing systems leads to changes in the cognitive systems involved in reading. They hypothesize that the reading skills and subskills triggered by the properties of two simultaneously learned orthographies are assimilated, leading to "cognitive and neural accommodation" (Lallier & Carriras, 2018, p. 392) and to the development of hybrid grain size reading strategies. For instance, a bilingual reader mastering both a transparent orthography and an opaque orthography is expected to process larger units when reading in their transparent orthography than a monolingual reader of the same transparent orthography, which affects the distribution of visual attentional resources and VAS skills (Lallier & Carreiras, 2018, p. 393).

Most of the evidence supporting the grain size accommodation hypothesis is currently limited to early simultaneous bilinguals (see Lallier et al., 2013a, 2016, 2018b, 2021). For example, Lallier et al. (2016, 2021) compared two groups of early bilingual children mastering either two transparent orthographies (Spanish and Basque) or one opaque and one transparent orthography (French and Basque, respectively) in tasks measuring phonological awareness and VAS in their common orthography, Basque. The two groups differed in terms of VAS, with the French–Basque distributing their attention resources more homogeneously. This result was attributed to experience with French, which, with its less consistent GPCs, has the effects of boosting VAS (Lallier et al., 2016) or favoring the contribution of VAS skills to reading (Lallier et al., 2021). By contrast, Spanish–Basque bilinguals showed a narrower VAS, yet outperformed French–Basque bilinguals in phonologically demanding tasks (Lallier et al., 2016). This advantage was attributed to their experience with two transparent systems, which enhances reliance on smaller phonological units, thus boosting phonological awareness. Crucially, this "transparent orthography advantage" was also observed in adult biliterate readers with dyslexia (Lallier et al., 2018b).

It is still unclear, however, whether and to what extent such transfer of reading skills and subskills is modulated by reading proficiency and/or experience in late biliterates. Furthermore, it is not clear whether crosslinguistic interactions on VAS are still visible in developmental dyslexia associated with a VAS deficit (Valdois, 2022).

[3]In addition to the orthographic depth of a language, other types of "large grains" such as morphological information have been shown to influence VAS skills (see Antzaka et al., 2019).

3. The present study

The aim of this study is to test whether the prediction of the grain size accommodation hypothesis in early simultaneous bilinguals (Lallier & Carreiras, 2018) on VAS holds true for late biliterates with and without developmental dyslexia. To this end, we tested high school students in Italy who had started learning English as an L2 at school. High school students typically represent a wide spectrum of L2 proficiency levels, albeit with more or less comparable exposure to English. The following questions are addressed:

RQ1 : Does (high) proficiency in an opaque nonnative orthography (English) modulate the VAS of individuals whose native language orthography (Italian) is highly transparent?

RQ2 : Are crosslinguistic accommodation processes similar in late biliterates with and without dyslexia?

Under the (visual) grain size accommodation hypothesis (Lallier & Carreiras, 2018), and given that experience with an opaque orthography may modulate the size of visual units that are processed while reading (Lallier et al., 2013a, 2016, 2021), we predict that reading and cognitive strategies triggered by more advanced English reading skills will transfer to the native orthography and affect the VAS of Italian L2 learners of English. Further, we expect the accommodation of VAS to be less visible in learners with developmental dyslexia who (may) present VAS limitations. To assess VAS, a visual-1-back task (Lallier et al., 2016) will be used. Participants have to detect the presence or absence of a target letter whose position within a previously briefly presented 5-consonant string varies. As a proxy measure of English and Italian reading experience, we assessed orthographic knowledge in each of these languages. This measure provides an estimate of how fluently and accurately participants can access their lexical (abstract) orthographic representations.

First, based on previous research showing that reading direction (Awadh et al., 2016) and orthographic depth (Lallier et al., 2013a) affect the allocation of attention resources on multi-letter arrays, we expect all participants to exhibit a strong leftward bias in the allocation of visual attention on the letter strings, in line with the properties of their transparent first language (L1). Irrespective of dyslexia, we thus predict better recognition of consonants in the leftmost relative to the rightmost position of the consonant string. Second, while a VAS bootstrapping effect is expected in late biliterates, only English orthographic proficiency but not Italian orthographic proficiency is expected to be a driving force. Thus, we compare the effect of Italian and English orthographic proficiency on VAS modulations to disentangle the impact of mastering an opaque nonnative (L2) orthography from the broader influence of advanced orthographic skills in the native language. In other words, higher levels of English (but not Italian) orthographic knowledge should correlate with a more homogenous distribution of visual attention resources across the consonant strings, reflected by similar target letter detection performance across all five positions. Finally, we predict that modulation of VAS as a result of higher English orthographic proficiency would be more visible in skilled readers relative to their peers with dyslexia due to a possible VAS deficit in the latter group (Bosse et al., 2007; Valdois, 2022).

4. Method

4.1. Participants and procedure

Ninety high school students participated in the study (age: $M = 17.03$; *standard deviation (SD)* = 1.41; range = 14.11–20.50).

https://doi.org/10.1017/S1366728925000124 Published online by Cambridge University Press

Twenty-nine participants had a formal diagnosis of dyslexia (DYS group), which was assessed by authorized Italian clinical institutes according to national regulations.[4] The remaining sixty-one participants had no diagnosis of dyslexia (TD group), but four had other specific learning disorders (e.g., dyscalculia and dysgraphia) and were thus excluded from the control sample. Eighty-eight participants were attending high school[5] at the time of the experiment. Two participants (one TD and one DYS) were attending university at the time of testing.[6] Overall, there was no age difference between the two groups ($p = .321$). All participants were native speakers of Italian and had started learning English as an L2 either in the first grade of primary school or kindergarten (Age of Onset: $M = 5.66$; $SD = 0.86$).[7] Participants attended three high schools with varying levels of foreign language (FL) instruction. The first, a linguistic gymnasium ($N = 39$), offered English, French and German, with students reporting an average of 3.67 hours of English per week ($SD = 0.62$, range = 3–5). The second, a gymnasium ($N = 17$), had either a language-focused or scientific curriculum, with students reporting 3.12 hours of English classes per week ($SD = 0.33$, range = 3–4). The third, an agrarian institute ($N = 32$), provided mandatory English, with students attending 2.84 hours of English classes weekly ($SD = 0.45$, range = 2–4).[8] (Appendix B) details the school curricula. Each DYS participant was matched with at least one TD control based on age, grade and school type.

Participants were tested individually in a quiet room at school. The experimental procedure was split into two sessions: one focusing on Italian and the other on English. Task instructions were provided in Italian and English, respectively. The language of communication between the researcher and the participant was always Italian. The order of the sessions was counterbalanced across participants. Each session lasted 40–60 minutes, with a gap of 4–7 days. The Italian session[9] included i) standardized tests to assess Italian reading skills, ii) a spoonerism task to assess phonological awareness skills, iii) a digit span task to assess phonological short-term/working memory skills (Monaco et al., 2013) and iv) a lexical decision task under articulatory suppression to measure orthographic knowledge (Montesano et al., 2020). The English session included i) a questionnaire to gather sociolinguistic information (Appendix B), ii) an orthographic choice task to assess orthographic proficiency (Olson et al., 1994) and iii) the visual-1-back task to assess VAS (Lallier et al., 2016), which was always administered at the end of the session.

4.2. Neuropsychological assessment

4.2.1. Italian reading skills

Standardized tests were used to assess reading fluency and accuracy in Italian to ensure that control participants had good lexical (real words) and sublexical (nonwords) reading skills (I and II high school grade: *MT Avanzate-3-Clinica*, Cornoldi et al., 2017; III to V high school grade: *Prove di lettura e scrittura MT 16–19*, Cornoldi & Candela, 2015; and university: *LSC-SUA* battery, Montesano et al., 2020). All participants read 112 real words divided into four lists (short frequent words, long frequent words, short infrequent words and long infrequent words) and 56 nonwords divided into two lists (short and long). Reading times and errors were calculated for both word and nonword reading, and Z-scores were computed according to standardized parameters, which accounted for participants' age.

4.2.2. Phonological short-term and working memory

Memory abilities were gathered to control for participants' ability to process phonologically demanding material (e.g., consonant letters) in the visual-1-back task. Phonological short-term and working memories were assessed with the forward and backward digit-span tasks (Monaco et al., 2013), respectively. The tasks include aurally presented digit strings of increasing length (3 to 9 digits in the forward version and 3 to 8 digits in the backward version). In the forward version, participants were asked to repeat the digits in the same order; in the backward version, they were asked to repeat them backward. If the repetition of the digit was correct, a one-digit longer string was presented. In case of mistakes, participants were presented with a different string of the same length. If two consecutive mistakes occurred with the same digit length, the task ended. The maximum number of digits that were correctly repeated was calculated.

4.2.3. Italian phonological awareness

Phonological awareness was measured with a spoonerism task. Ten experimental items were constructed, consisting of a pair of disyllabic real words. Participants were instructed to switch the first sound of the two words as quickly as possible (e.g., prompt: /**s**alto/ /**d**una/; target: /**d**alto/ /**s**una/), which always resulted in the production of two disyllabic nonwords. The task was not time-constrained. Responses in the spoonerism were assigned 2 points if participants managed to switch the two phonemes correctly and produced the correct target nonwords. If phonemes were switched correctly but the target nonword was incorrect (e.g., prompt: /**s**alto/ /**d**una/; target: /**d**alt**a**/ /**s**un**o**/), the response was assigned 1 point. If the phonemes were not switched correctly, the response received 0 points. Response time (RT) was measured as the duration between the conclusion of the prompt and the conclusion of the answer. Finally, a speed–accuracy trade-off score was computed using the *bis* function (Liesefeld & Janczyk, 2019) in R

[4]Diagnostic tests assessing reading accuracy/fluency, writing and calculation are used in clinical contexts. The diagnostic threshold is typically set below the 5th percentile for reading accuracy and below 2SD for reading fluency (Cornoldi et al., 2022).

[5]In Italy, high school starts at 14 years. Typically, there are five grades (3 to 5 for vocational training).

[6]They had graduated from the same high schools as the other participants. Additionally, they were twins (one with a formal diagnosis of dyslexia). Given their close age relative to the rest of the sample, they were kept in the study.

[7]In Italy, reading is first acquired in Italian. Children start to read in English only in the second or third grade typically through the same instruction used for Italian (phonics). Exposure to English is typically 1–2 hours a week, at least until the 6th grade.

[8]As noted by a reviewer, the number of foreign languages (FLs) studied by participants may also play a role and deserve further investigation. However, this would require data on participants' proficiency levels in each language. In our case, the other FLs learned (mostly French, Spanish, German) are orthographically more transparent than English, suggesting that, even if they *had been* mastered at higher proficiency levels than English, they are unlikely to boost VAS even further than English. Moreover, our data suggest a lack of correlation between the number of FLs studied by participants and their accuracy in the VAS task (TD: $r(49) = .18$, $p = .190$; DYS: $r(27) = .13$, $p = .498$).

[9]Both sessions started with an eye-tracking task and included vocabulary size tasks. Details on participants' performance in the LexTALE assessing English vocabulary size (Lemhöfer & Broersma, 2012) can be found in (Appendix C). Participants' performance in the LexTALE and in the Orthographic Choice Task (Olson et al., 1994) was highly correlated (TD: $r(49) = .66$, $p < .001$; DYS: $r(27) = .55$, $p = .002$). We focused on the latter because it taps into orthographic knowledge and thus serves as a measure of reading proficiency.

https://doi.org/10.1017/S1366728925000124 Published online by Cambridge University Press

(version 4.2.1). The *bis* function generates a balanced integration score (BIS). This score standardizes both the average of correct responses for each participant and the average RT for those correct responses. Subsequently, it computes the difference between the standardized accuracy and RT scores (see Liesefeld & Janczyk, 2019, p. 42).

4.2.4. Italian orthographic knowledge

Italian orthographic knowledge was assessed using the lexical decision task under articulatory suppression from the LSC-SUA diagnostic battery (Montesano et al., 2020). The term articulatory suppression refers to the fact that participants had to make a lexical decision, while continuously repeating the syllable <*la*>, which inhibits access to the phonological representations of the words they were reading. Although this task was not designed to assess orthographic knowledge in Italian, we believe that articulatory suppression enables testing how fluently and accurately abstract orthographic representations of real words are accessed, thereby indirectly engaging participants' orthographic knowledge. Indeed, articulatory suppression prevents the use of phonological decoding procedures while performing the lexical decision task. The tests included four lists of words (N = 60) and nonwords (N = 60) presented in a mixed block. Participants were asked to mark as many real words as possible in one minute while ignoring nonwords. The number of accepted nonwords was subtracted from the number of correct responses to compute the total score (max. 60).

4.2.5. English orthographic knowledge

English orthographic knowledge was measured with the orthographic choice task (Olson et al., 1994) run on Gorilla (Anwyl-Irvine et al., 2020). The task included 80 pairs of words and pseudo-homophones (e.g., *interesting* and **intresting*). Participants were instructed to click on the correctly spelled word as quickly as possible. The task was not time-constrained, and items were presented in randomized order. Accuracy scores and RTs in the orthographic choice task were computed. To make the measure comparable to the Italian one[10] (which was time-constrained), a trade-off between speed and accuracy was assessed using the *bis* function (Liesefeld & Janczyk, 2019) in R.

4.3. Visual-1-back task

The visual-1-back task was used to measure participants' VAS. We followed Lallier et al. (2016) and created 80 five-consonant strings (50 experimental +30 distractors) using Python. The task can reveal potential biases in the allocation of visual attention resources because no consonant string corresponds to existing words in Italian or English, and thus, no lexical item in the orthographic or phonological lexicon can be activated (Lallier et al., 2016). Strings were created using 10 consonants (B, C, F, H, N, Q, S, T, V and Z). We avoided orthographically similar consonants (e.g., M and N) to facilitate letter recognition. The crucial independent variable of this task is the position in which the consonant appeared within the string (1 to 5). Each consonant was thus used five times, once per position (e.g., **B**CVTH, Z**B**HNT, HZ**B**TV, QFV**B**N, ZQSH**B**). The task was implemented on Gorilla (Anwyl-Irvine et al., 2020). It began with the display of a fixation cross at the center of the screen (1024 x 768 pixels) for a duration of 500 ms, followed by a blank screen (100 ms). Subsequently, the consonant string was displayed in the center of the screen for 200 ms with double spacing between each consonant to minimize lateral masking effects (Lallier et al., 2018b). Then, a screen without time constraints appeared, presenting a single consonant that was either part of the consonant string (target) or not (filler). Participants were instructed to click YES if they believed the consonant was present in the preceding string or NO if they thought otherwise. Unlike traditional global/partial report tasks, which require participants to orally report the entire string (global) or a single cued letter (partial), the visual-1-back task does not involve letter naming. Consequently, phonological processing skill contribution to the task, which could impede the performance of dyslexic participants (Goswami, 2015; Liu et al., 2023), is substantially reduced and most of the variance observed in the performance of the task would thus be attributable to VAS skills, rather than phonological skills (i.e., accessing and remembering the phonological representation of the consonants). Participants had approximately a 62% chance of correctly responding YES. As noted by Lallier et al. (2016), when the probability of giving a correct response (in this case, YES) is relatively high, participants tend to underestimate the chance level.

We computed accuracy (the proportion of correct responses for each consonant position) to account for the amount of information that can be processed and encoded in short-term memory (STM) (Lallier et al., 2013a). A signal detection theory (SDT) analysis was also conducted to account for participants' decision biases when performing the task and is presented as a complementary analysis in (Appendix A). The SDT analysis focuses on a "pseudo" d prime (d') score and on the C criterion (see (Appendix A) for a more thorough explanation of each measure), allowing for a deeper interpretation of the accuracy results presented below.

5. Results

5.1. Neuropsychological assessment

For all background measures, dependent variables were analyzed as a function of Group (TD versus DYS) and Age. All initial models (run with the *lm* or *glm* functions in R, depending on the distribution of the response variable) included an interaction between Group and Age (formula = response ~ Group * Age). Nonsignificant interactions were dropped to analyze the main effects of Group and Age separately (formula = response ~ Group + Age). The simple linear models assessing participants' performance in the standardized reading tests, instead, did not include Age, in that Z-scores were calculated following standardized parameters that account for participants' age.

TDs significantly outperformed DYS participants in all reading domains (Table 1). Six participants from the TD group exhibited

[10]We acknowledge that the Italian and English tests are not directly comparable. First, they differ significantly in their administration modality. While the Italian test requires the simultaneous presentation of all items, alongside the performance of two tasks (lexical decision + articulatory suppression), the English task does not. Additionally, the English task exclusively incorporates pseudo-homophones, whereas the Italian test encompasses both pseudowords (e.g., **sol**t**ato* > *soldato*, "soldier") and nonwords (e.g., **amanile*), which serve as an indicator of decoding abilities. Nevertheless, given the difficulties in developing a test analogous to the one developed by Olson et al. (1994) for languages with a transparent orthography, we opted for Montesano et al.'s (2020) task in that the articulatory suppression helps us tap into orthographic processing by "blocking" the phonological loop. Further, we believe both tests to be reliable indicators of the speed (and accuracy) at which readers can access abstract orthographic representations. Finally, the significant correlation between the two tests ($r(78) = .66$, $p < .001$) suggests that they capture similar variance and tap into similar processing levels.

https://doi.org/10.1017/S1366728925000124 Published online by Cambridge University Press

Table 1. DYS and TD participants' performance in the screening reading tests. *p < .05*, p < .01**, p < .001****

	DYS			TD			
	M	*SD*	range	*M*	*SD*	Range	β (*p*)
Real word accuracy	−2.80	2.53	−9.07 – 1.04	−0.06	0.82	−2.36 – 1.18	2.74***
Real word fluency	−4.46	2.83	−14.12 – −0.58	−0.73	1.18	−4.97 – 1.65	3.44***
Nonword accuracy	−2.97	2.97	−11.78 – 0.75	−0.28	1.29	−4.55 – 1.29	2.75***
Nonword fluency	−3.62	3.45	−19.39 – −0.44	−0.36	1.15	−4.58 – 1.80	2.69***

Table 2. DYS and TD participants' performance in the forward and backward digit span task (Phonological STM and WM, respectively), Italian Orthographic Knowledge (IOK), English Orthographic Knowledge (EOK) and speed–accuracy trade-off scores in the spoonerism task (Phonological Awareness, PA). The table reports the mean, standard deviations and range for each Group (DYS versus TD). For each measure, model results are reported for Group, Age and the interaction between the two when significant. "glm" models were used for Phonological STM, WM and IOK. "lm" models were used for EOK and PA. *p < .05*, p < .01**, p < .001****.

				Group	Age	Age*Group
	Mean	*SD*	*range*	χ^2_{LR} (*p*)	χ^2_{LR} (*p*)	χ^2_{LR} (*p*)
Phonological STM						
DYS	5.97	0.91	4–8	1.14 (n.s.)	0.00 (n.s.)	(n.s.)
TD	6.63	1.11	4–9			
Phonological WM						
DYS	4.24	1.90	0–8	6.33*	1.54 (n.s.)	(n.s.)
TD	5.39	1.40	3–8			
Italian Orthographic Knowledge (IOK)						
DYS	29.55	10.18	12–50	153.47***	17.83***	(n.s.)
TD	46.35	9.36	25–59			
				***F* (*p*)**	***F* (*p*)**	***F* (*p*)**
English Orthographic Knowledge (EOK)						
DYS	−1.31	1.93	−7.58 – 2.30	54.58***	2.24 (n.s.)	(n.s.)
TD	0.89	0.77	−0.79 – 2.47			
Phonological Awareness (PA)						
DYS	−1.44	2.12	−6.47 – 1.68	11.36***	10.23**	7.83**
TD	0.99	0.91	−2.12 – 2.13			

poor reading performance across all reading domains and were therefore excluded from further analyses. The final sample included 29 participants with dyslexia and 51 age-matched controls. Table 2 reports DYS and TD participants' results and the statistical analysis of the background measures.

5.2. Visual-1-back task

The data analysis on response accuracy was conducted using generalized linear mixed effect models (assuming a binomial distribution) with the *glmer* function from the *lme4* package (Bates et al., 2015) in R (version 4.2.1). The *emmeans* and *emtrends* functions (*emmeans* package; Lenth, 2024) were used for the post hoc analyses of interaction terms. Participants' accuracy (binary coded: 1 = correct; 0 = incorrect) in the visual-1-back task was analyzed as a function of Consonant Position (1 to 5) and Group (TD versus DYS). Further, we assessed the effects of i) English Orthographic Knowledge (L2) and ii) Italian Orthographic Knowledge (L1) in modulating participants' VAS skills and biases in allocating their visual attention resources when presented with an unknown string of consonants. Further, the models also controlled for Phonological STM skills[11] to control for their potential contribution to VAS task performance, which might rely on the automatic retrieval of the phonological labels of letters in a given string. For each initial model, the random effect structure was kept maximal (Barr et al., 2013) and thus included random intercepts for Participants and Items and allowed for a random slope of Consonant Position over Participants, which was dropped in cases of convergence issues. A detailed report of the analysis is available in the Supplementary Materials (Appendix C).

[11]The Phonological STM/WM score was obtained by averaging participants' performance in the two versions of the digit span task.

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5.2.1. Effects of English orthographic knowledge on VAS skills

The best-fit model predicted accuracy as a function of a three-way interaction between English Orthographic Knowledge, Group and Consonant Position. Due to convergence issues, the random effect structure only included random intercepts for Participants and Items. The model yielded a significant effect of Consonant Position (χ^2 = 22.10, p < .001), English Orthographic Knowledge (χ^2 = 7.90, p = .005) and Phonological STM (χ^2 = 8.33, p = .004), showing that both DYS and TD were significantly better at detecting consonants in the two leftmost and central positions and that higher Phonological STM skills and English Orthographic Knowledge increased accuracy in both groups (Figure 1). Group alone was not significant (χ^2 = 1.55, p = .213). The three-way interaction between Group, Consonant Position and English Orthographic Knowledge was significant (χ^2 = 9.70, p = .046), showing that the effect of English Orthographic Knowledge modulated TD and DYS participants' performance differently in the task, depending on the Consonant Position (Figure 2). The lower-level interactions between Consonant Position and English Orthographic Knowledge (χ^2 = 6.49, p = .165), between Consonant Position and Group (χ^2 = 3.37, p = .498) and between English Orthographic Knowledge and Group (χ^2 = 0.88, p = .349) were not significant.

Post hoc analyses show that while English Orthographic Knowledge significantly and positively influenced DYS participants' performance when the consonant was in first (β = 0.40, *standard error (SE)* = 0.14, z = 2.81, p = .005) and second (β = 0.31, *SE* = 0.14, z = 2.20, p = .028) positions, the effect was null when the consonant was in third, fourth and fifth positions (Table 3). As for TDs, English Orthographic Knowledge significantly improved participants' performance when the consonant was in the rightmost position (β = 0.83, *SE* = 0.28, z = 2.95, p = .003), while its effect was marginal or null in the other positions (Table 3).

The post hoc analysis also revealed that while the overall difference between TD and DYS participants' accuracy was not significant, significant differences emerged between the two groups at high English Orthographic Knowledge levels (+1SD) with TD outperforming DYS when the consonant appeared in third (β = −0.77, *SE* = 0.38, z = −2.00, p = .046) and fifth (β = −0.75, *SE* = 0.36, z = −2.08, p = .038) positions, while the difference was only marginal in fourth position (β = −0.68, *SE* = 0.36, z = −1.90, p = .058), as reported in Table 4. The comparison between TD and DYS at each consonant position and English orthographic knowledge level is illustrated in Figure 3.

Last, we compared accuracy across the leftmost and rightmost consonant positions for each group and across different levels of English orthographic knowledge (low: -1SD, high: +1SD) to determine whether the anticipated "position effect" (accuracy is expected to be higher in the leftmost position, reflecting a leftward bias in the allocation of attentional resources) was mitigated by higher proficiency in English orthographic skills. DYS participants were more accurate in the leftmost position as compared to the rightmost position, irrespective of English orthographic knowledge (low: β = 0.64, *SE* = 0.22, z = 2.91, p = .036; high: β = 1.22, *SE* = 0.38, z = 3.18, p = .015). By contrast, the TD group showed differences in accuracy between the rightmost and leftmost positions in the string, but these were only significant for TDs with low orthographic knowledge skills in English (β = 2.05, *SE* = 0.58, z = 3.51, p = .004) and not for TDs with high orthographic knowledge skills (β = 0.50, *SE* = 0.30, z = 1.69, p = .918).

5.2.2. Effects of Italian orthographic knowledge on VAS skills

A second model was employed to explore how Italian Orthographic Knowledge affects VAS abilities in typical and dyslexic readers. As pointed out above, this analysis was run to ensure that the effect observed in the previous analysis was driven by participants' exposure to the English orthography rather than by better reading skills in their L1. Importantly, Italian orthographic proficiency and English orthographic proficiency were strongly correlated overall

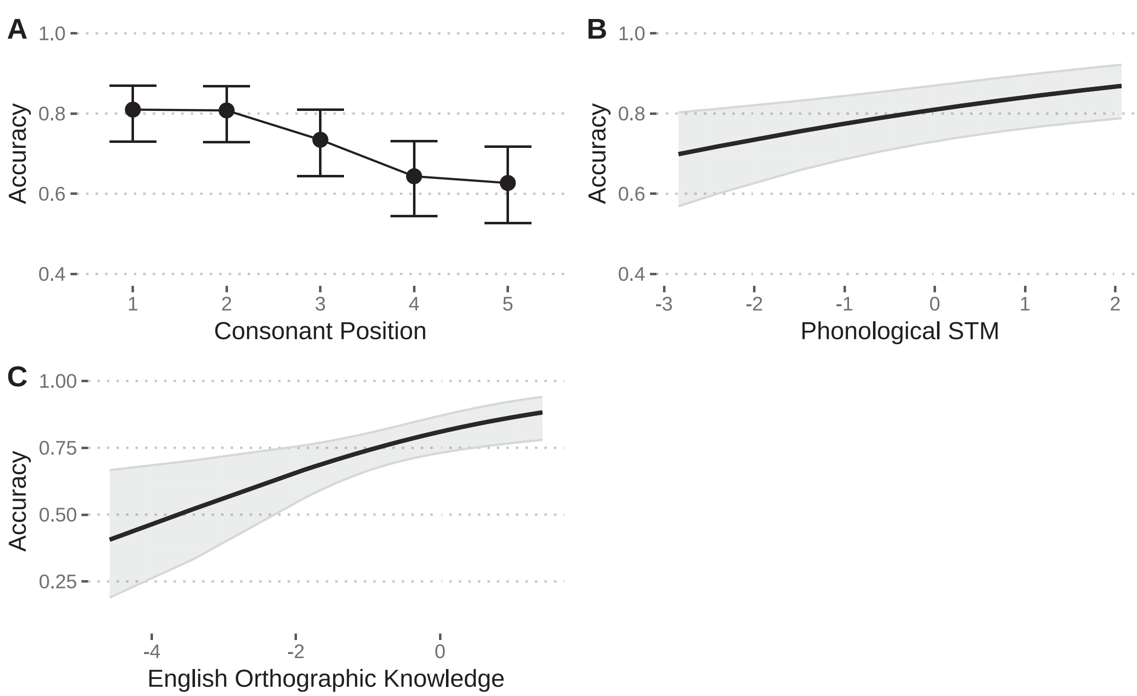

Figure 1. Main effects of Consonant Position (A), Phonological STM (B) and English Orthographic Knowledge (C) on participants' accuracy in the VAS task. The main effects of Consonant Position (p < .001), Phonological STM (p = .004) and English Orthographic Knowledge (p = .005) were all significant. None of the three factors significantly interacted with Group alone.

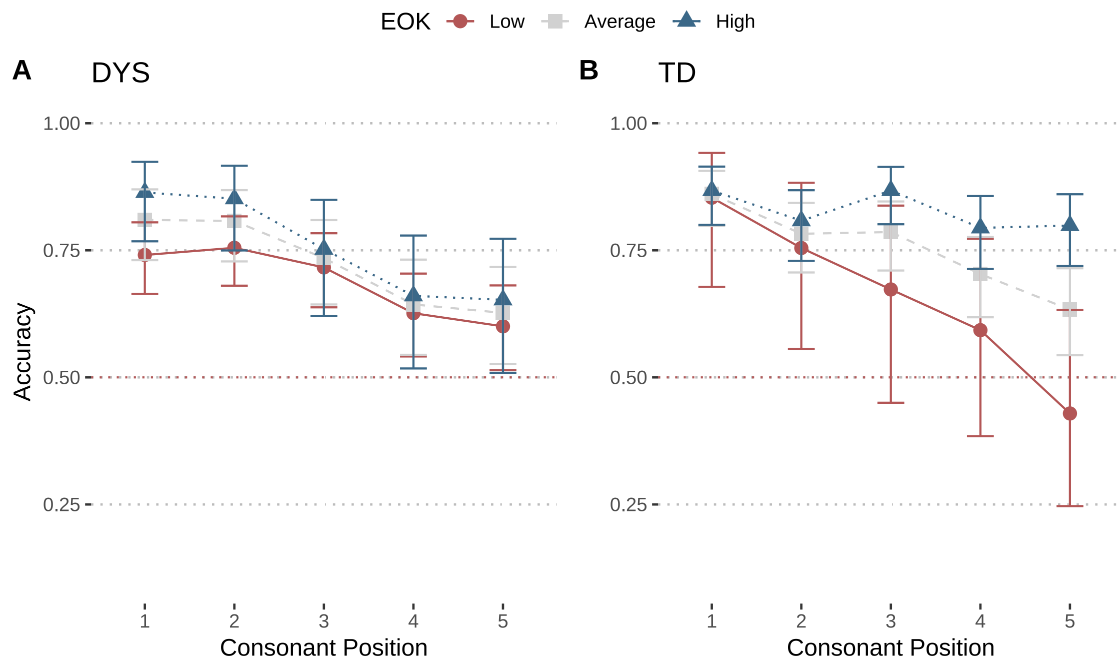

Figure 2. Effect of low (-1SD), average (*M* = 0) and high (+1SD) English Orthographic Knowledge (EOK) at each Consonant Position for DYS (A) and TD (B). The three-way interaction was significant (*p* = .046).

Table 3. Effect of English Orthographic Knowledge (EOK) on TD and DYS participants' accuracy by Consonant Position (CP)

Formula: *emtrends*(model, pairwise ~ Group | CP, var = "EOK," infer = T, adjust = "bonferroni")					
Group	CP	Estimate	*SE*	*z*	*p*
DYS	**1**	**0.40**	**0.14**	**2.81**	**.005**
	2	**0.31**	**0.14**	**2.20**	**.028**
	3	0.09	0.14	0.66	.507
	4	0.07	0.13	0.55	.579
	5	0.11	0.13	0.83	.406
TD	1	0.06	0.34	0.17	.862
	2	0.16	0.30	0.53	.597
	3	0.58	0.31	1.85	.065
	4	0.49	0.28	1.71	.087
	5	**0.83**	**0.28**	**2.95**	**.003**

($r(78) = .66$, $p < .001$), but this correlation was stronger for DYS participants ($r(27) = .58$, $p = .001$) than for TD participants ($r(49) = .29$, $p = .041$). A *glmer* model was used to investigate participants' accuracy as a function of a three-way interaction between Consonant Position, Group and Italian Orthographic Knowledge. Initially, Age was included in the model based on prior analyses indicating a significant interaction between Group and Age when predicting Italian Orthographic Knowledge (see Table 2). However, due to convergence issues, Age was dropped. The best-fit model further controlled for Phonological STM and included random intercepts for Participants and Items. No random slope was included due to convergence issues. The model yielded a significant effect of Consonant Position ($\chi^2 = 22.49$, $p < .001$) and Phonological STM ($\chi^2 = 11.57$, $p = .001$), showing that both TD and DYS were more accurate when the target consonant appeared in the leftmost positions and that Phonological STM significantly and positively increased participants' performance (Figure 4). The effect of Group alone was not significant ($\chi^2 = 1.53$, $p = .217$), nor was the effect of Italian Orthographic Knowledge alone ($\chi^2 = 2.59$, $p = .108$), or the three-way interaction between Italian Orthographic Knowledge, Group and Consonant Position ($\chi^2 = 6.94$, $p = .139$). The lower-level interactions were not significant either (Consonant Position by Italian Orthographic Knowledge: $\chi^2 = 7.76$, $p = .101$; Consonant Position by Group: $\chi^2 = 7.47$, $p = .113$; Italian Orthographic Knowledge by Group: $\chi^2 = 0.24$, $p = .622$).

6. Discussion

This study tested the predictions of the grain size accommodation hypothesis (Lallier & Carreiras, 2018) in Italian-English late

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Table 4. Comparison of DYS versus TD performance in all Consonant Positions (CPs) at low (-1SD), average (M = 1) and high (+1SD) English Orthographic Knowledge (EOK) levels

Formula: *emmeans*(model, pairwise ~ Group | EOK | CP, at = list(EOK = c(−1,0,1)), adjust = "bonferroni")

Contrast	EOK	CP	Estimate	*SE*	*z*	*p*
DYS – TD	Low (−1SD)	1	−0.71	0.53	−1.34	.180
	Average (M = 0)		−0.37	0.30	−1.25	.213
	High (+1SD)		−0.03	0.40	−0.08	.936
DYS – TD	Low (−1SD)	2	0.00	0.48	0.00	.996
	Average (M = 0)		0.16	0.28	0.55	.583
	High (+1SD)		0.31	0.39	0.80	.424
DYS – TD	Low (−1SD)	3	0.20	0.49	0.42	.674
	Average (M = 0)		−0.28	0.27	−1.03	.303
	High (+1SD)		**−0.77**	**0.38**	**−2.00**	**.046**
DYS – TD	Low (−1SD)	4	0.14	0.45	0.31	.755
	Average (M = 0)		−0.27	0.26	−1.05	.295
	High (+1SD)		−0.68	0.36	−1.90	.058
DYS – TD	Low (−1SD)	5	0.69	0.44	1.57	.116
	Average (M = 0)		−0.03	0.26	−0.11	.914
	High (+1SD)		**−0.75**	**0.36**	**−2.08**	**.038**

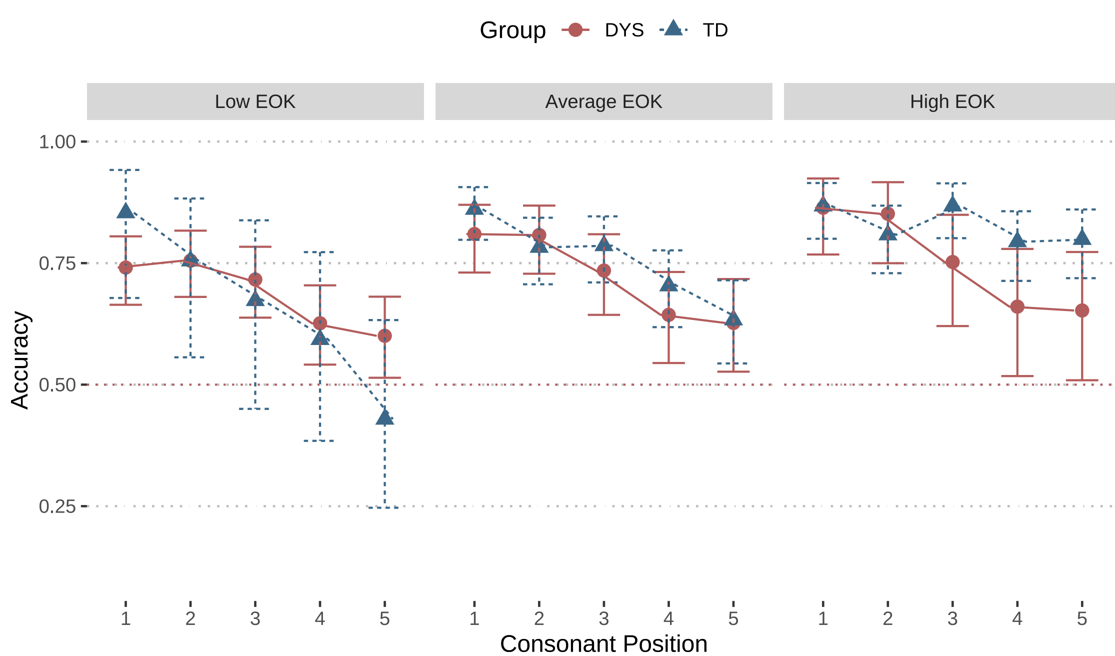

Figure 3. Comparison between DYS and TD performance at each Consonant Position and level of English Orthographic Knowledge (EOK) – *low EOK*: -1SD, *average EOK:* M = 0 and *high EOK:* +1SD. The comparison of DYS and TD participants' accuracy was significant in the third (p = .046) and fifth (p = .038) Consonant Position at high EOK levels (right panel).

biliterates with and without developmental dyslexia. Specifically, we assessed whether reading proficiency in a nonnative opaque orthography (English) modulates the VAS capacity of Italian (transparent orthography) learners (RQ1), comparing readers with and without dyslexia (RQ2). Based on previous findings (e.g., Awadh et al., 2016; Lallier et al., 2013a) and theoretical frameworks of orthographic processing (Grainger et al., 2016), we expected a leftward bias in the allocation of visual attention resources driven by L1 Italian, requiring left-to-right analysis. This was expected irrespective of dyslexia. However, participants with higher English orthographic knowledge were predicted to distribute their visual–attentional resources more homogeneously across letter strings due to their experience with an opaque orthography that requires the processing of larger visual grains (Lallier & Carreiras, 2018). In contrast, we expected no VAS modulation to be driven by Italian orthographic knowledge, given that VAS skills may be less important in a transparent orthography (Awadh et al., 2016; Gavril et al., 2021). Further, we compared typically developing and dyslexic late

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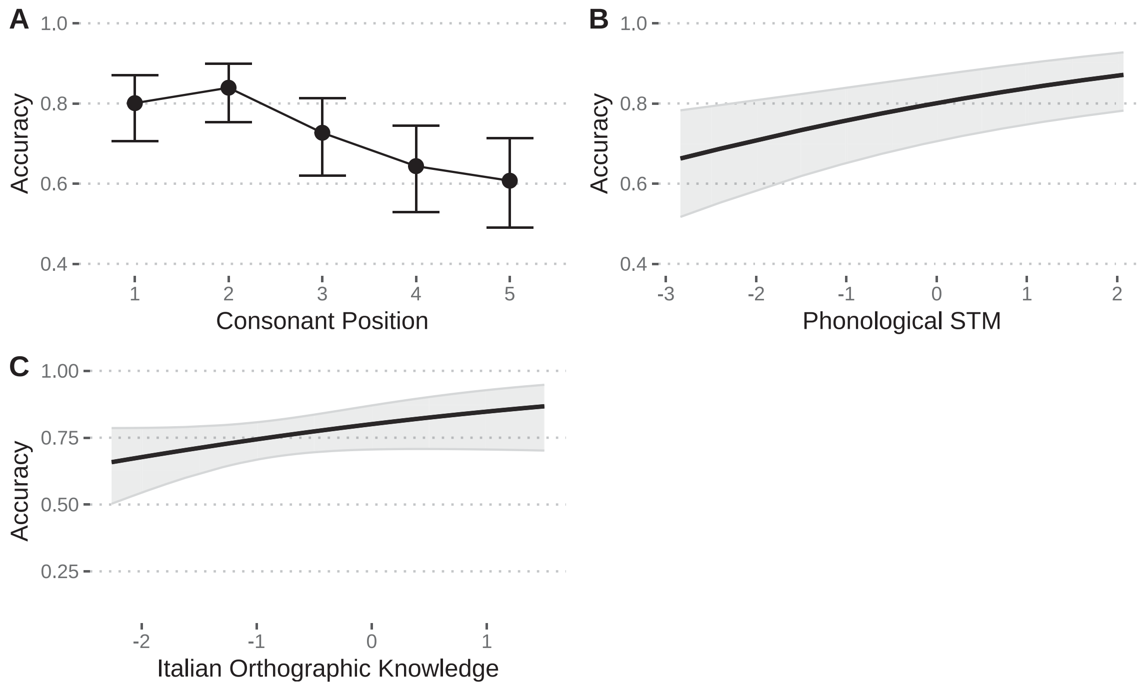

Figure 4. Main effects of Consonant Position (A), Phonological STM (B) and Italian Orthographic Knowledge (C) on DYS and TD's accuracy. The main effects of Consonant Position ($p < .001$) and Phonological STM ($p = .001$) were significant, while Italian Orthographic Knowledge was not ($p = .108$). None of the three factors significantly interacted with Group alone.

biliterates to assess whether such orthography-specific VAS modulations are also possible in the presence of a potential VAS deficit.

To evaluate VAS abilities, we used a visual-1-back task (Lallier et al., 2016). Participants' performance (in terms of accuracy) was analyzed as a function of i) consonant position, ii) English and iii) Italian orthographic knowledge. In line with Lallier et al. (2013a), we interpreted accuracy as an index of the amount of information that is transferred to and retained in visual short-term memory, indicating the size of the visual grains encoded during orthographic processing. The purpose of these analyses was threefold: (i) assessing whether the predicted leftward bias would be attenuated by experience with the English orthography, (ii) comparing the effect of Italian orthographic knowledge to the effect of English orthographic knowledge (to disentangle the impact of mastering the English orthography from the impact of mastering Italian) and (iii) comparing the effects of Italian and English orthographic knowledge on potential VAS modulations between typical and dyslexic learners. As mentioned above, an SDT analysis (Appendix A) was conducted to investigate participants' decision biases linked to attentional processes (Müller & Findlay, 1987).

6.1. Crosslinguistic interaction in VAS in typical L2 learners

Our study is the first to demonstrate that orthography-specific VAS modulations can be influenced by exposure to a nonnative opaque orthography (English) and that the predictions of the grain size accommodation hypothesis (Lallier & Carreiras, 2018) extend to late biliterates. Our analysis of accuracy scores showed that higher English orthographic knowledge (arguably as a result of higher reading experience) modulated the size of VAS in TD participants: Participants with high English orthographic knowledge were good at identifying target consonants irrespective of their position within the string, thus showing a more homogeneous distribution of attention resources when presented with an unknown string of letters, which was not accompanied by a drop in their accuracy scores (Figure 2). Post hoc analyses showed that English orthographic knowledge was especially predictive of accuracy when the consonant was presented in the rightmost position within the string (Table 3). In contrast, for typical readers with lower English orthographic knowledge, accuracy gradually decreased from the left to the right, thus showing a reduced VAS capacity and a stronger bias in allocating attention resources toward the leftmost positions. This is in line with Lallier et al. (2013a), who showed that Welsh–English bilinguals have a smaller VAS than English monolinguals, as well as higher-quality probe encoding when targets were presented on the left side of the consonant strings (indicated by P3b amplitude), owing to experience with Welsh (transparent orthography).

Highly proficient typical readers showed a W-shaped pattern of visual attention distribution (Figure 2, panel B), in line with Grainger et al.'s (2016, p. 172) theoretical framework of visual constraints on multi-letter array identification, according to which W-shaped patterns of visual attention distribution can be influenced by letter acuity and crowding effects. In other words, greater proximity to the fixation point enhances letter visibility (acuity), while increased spacing around the letter diminishes crowding effects. Building upon this observation, we hypothesize that participants with higher orthographic knowledge in English, having developed an appropriate visual attention window size for reading in English (five graphemes; Perry & Long, 2022, p. 6), are more inclined to focus their attention on the middle when presented with an unknown string of letters, in addition to distributing their attentional resources more homogeneously to accurately detect consonants regardless of their position within the string. Thus, our results support the hypothesis that learners with advanced orthographic expertise in English may accommodate their cognitive processing

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strategy, resulting not only in improved task accuracy but also in shifts in their cognitive attentional priors, affecting how they approach spatial information processing. This was further supported by the results of the SDT analysis (Appendix A), which suggest that typical readers with high orthographic proficiency in English are less sensitive to the leftmost letter in the string and show overall less positional biases, thus reflecting higher sensitivity to the statistical regularities of the English orthography (Müller & Findlay, 1987; Xu et al., 2023). By contrast, typically developing participants with lower orthographic proficiency in English were shown to have stronger attentional biases toward the left side of the consonant string, in line with previous studies (e.g., Lallier et al., 2013a). This was supported by their significantly higher accuracy when the consonant was in the first position compared to the fifth position. Crucially, we cannot rule out that the effect observed in the high-proficiency (TD) late biliterates may be due to the VAS task being administered at the end of the English session, thus potentially triggering an "English-like," large-grain reading strategy. However, whether the linguistic context modulates reading strategies in late biliterates remains an open question and requires further research.

As discussed above, a main effect of consonant position (i.e., higher accuracy when the consonant appeared in the leftmost position) was found across models, regardless of whether English or Italian orthographic knowledge was considered. This is in line with Grainger et al. (2016), who predict a first-letter advantage in visual processing irrespective of orthographic depth. Indeed, a first-letter advantage in letter recognition was previously demonstrated in native speakers of English (Scaltritti & Balota, 2013) in addition to skilled readers of Italian (Ripamonti et al., 2018). However, while higher proficiency in English orthography appears to mitigate this positional effect, as extensively discussed above, better Italian orthography skills do not have the same effect, neither on accuracy data nor on their decision (or attentional) criterion shown by the SDT analysis (Appendix A).

6.2. Crosslinguistic interaction in VAS in L2 learners with dyslexia

Our second research question concerned the differences between typical readers and those with dyslexia in their VAS abilities and modulations. Interestingly, when accuracy was operationalized as a function of consonant position and orthographic knowledge (in both Italian and English), group differences only emerged at high levels of English orthographic knowledge, when the consonant was presented in the rightmost position of the strings (Table 4). This suggests that, in terms of accuracy, both groups performed similarly, and distinctions primarily emerged when considering English orthographic proficiency. Crucially, this was not the case when Italian orthographic knowledge was considered. One possible explanation is that VAS is less discriminative of dyslexia when only transparent languages (like Italian) are considered. In contrast, VAS becomes discriminative of dyslexia when trained further as a result of the experience with an opaque orthography (English, in this case). In other words, VAS deficits in dyslexia may be less visible in transparent languages (irrespective of proficiency) in that a more homogeneous distribution of attentional resources is not required for accurate reading.

The effect of English orthographic proficiency on VAS performance differed significantly between dyslexic and typical learners, irrespective of whether accuracy, d prime score or attentional biases (C criterion) were considered (Appendix A). While English orthographic knowledge improved typical readers' accuracy when the consonant was in the rightmost position, as discussed above, in dyslexic participants its effect was only significant when the consonant was in the first or second position on the left (Table 3). Thus, individuals with dyslexia consistently direct their attention to the leftmost position of the string, regardless of their orthographic proficiency in English. Based on these results, we argue that individuals with dyslexia may have more difficulties than typical readers in accurately encoding letters appearing on the right of a multielement array within a single-eye fixation, even when their orthographic proficiency in English is high. In other words, our data show that English orthographic proficiency does not enhance the span of visual attention in dyslexia as much as in typical readers. One possible interpretation for this result is a VAS deficit in dyslexia (Valdois, 2022), which is further supported by the significant group differences that emerged in the SDT analysis (Appendix A). If VAS skills are deficient, they may be less malleable and thus less prone to crosslinguistic modulations. Indeed, the lack of VAS modulations driven by L2 orthographic proficiency in the SDT analysis seems to suggest that the cognitive priors modulating processing and attention biases are less flexible in individuals with dyslexia. An alternative explanation for the consistent leftward bias in dyslexic participants is their tendency to favor sublexical over lexical reading strategies (Borleffs et al., 2019).

It should be noted that while VAS skills (as indexed by accuracy) in individuals with dyslexia were not modulated by English orthographic proficiency to the same extent as in typical readers, a less strong yet significant VAS modulation was still observed. In particular, dyslexics with advanced orthographic proficiency in both English and Italian demonstrated higher accuracy in detecting consonants primarily in the first three positions from the left, although statistical differences were not evident in the third position, possibly due to the improved letter acuity induced by the fixation cross displayed before the consonant string. This may indicate that more reading experience leads to VAS modulation also in readers with dyslexia, though to a lesser degree than in typical readers. As pointed out above, Italian and English differ in the size of the visual–attentional window required for reading (Perry & Long, 2022). Thus, while individuals with dyslexia do not appear to have developed their VAS capacity to allow for efficient reading in English (five graphemes), as shown by their lower accuracy when the target consonants appeared in the rightmost position despite higher English reading proficiency levels, those with higher orthographic knowledge in their L1 and L2 have developed at least the maximum VAS size required for reading in Italian (three graphemes). It remains open whether this effect is driven by English or Italian orthographic knowledge – and by implication, by higher experience with the English or Italian orthography – because the two were strongly correlated in this group ($r(27) = .58$, p = .001). Finally, it should be highlighted that our models show a significant, positive effect of English orthographic proficiency in predicting accuracy in the VAS task, but not of Italian orthographic proficiency, irrespective of group or consonant position. This may indicate a general visual–attentional processing advantage associated with learning a nonnative opaque system, at least for learners whose native language orthography is transparent.

6.3. Limitations and future directions

Our results show a relation between VAS and L2 orthographic proficiency in late biliterates. However, one limitation is that we did not include a VAS task with nonlinguistic stimuli. Although we

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controlled for phonological STM, this compromises the claim of a VAS deficit independently of verbal abilities in individuals with dyslexia. To delve deeper into the investigation of visual processing and VAS deficits in dyslexia, future studies could integrate tasks encompassing both linguistic and nonlinguistic stimuli, similar to Ziegler et al. (2010) and Valdois et al. (2012). Furthermore, behavioral measures have limitations, as they involve motor abilities alongside visual attention (participants had to click on YES/NO). In order to corroborate the validity of our findings, forthcoming studies could compare behavioral results to more sensitive measures, such as event-related potential (ERP) (Lallier et al., 2013a) or eye tracking. The latter could be used, for instance, to investigate the location of the first fixation when the string is presented. Finally, more studies on crosslinguistic VAS modulations in late biliterates could test different language combinations.

While our study has provided insights into how orthographic proficiency in an L2 may lead to VAS modulations, some questions remain unanswered. One emerging question is whether a certain L2 experience threshold needs to be reached before modulations in visual processing skills can be observed and whether this threshold differs for learners with reading impairments. Second, future studies could investigate the contribution of additional FLs in the modulation of reading-related cognitive skills, such as VAS. For example, what happens to learners of an opaque L2 (like English), whose L1 is transparent (like Italian), but who acquire another opaque L3 (like French)? Is there a cumulative effect on VAS? Finally, it would be interesting to investigate potential crosslinguistic transfer in visual processing in (late) L2 learners of a transparent L2 whose native language orthography is opaque, for example, L1 English learners of Spanish or Italian. While modulation of VAS skills would mostly be driven by opaque orthographies (as extensively discussed above), it is possible that learning a transparent orthography boosts the ability to focus visual attention resources on smaller visual units (see Iniesta et al., 2023), owing to consistent GPCs which enhance the processing of smaller (visual) grains and possibly reduce crowding effects (Lallier et al., 2018a). Finally, longitudinal studies could also help better clarify the nature and directionality of the relationship between late biliteracy and cognitive processes (such as VAS) involved in reading.

7. Conclusion

We examined the influence of orthographic proficiency in a late-acquired L2 (English) on the VAS of L1 Italian speakers with and without developmental dyslexia. We showed that acquiring a nonnative opaque orthography boosts VAS abilities in L2 learners whose native language is highly transparent. This supports the hypothesis that typically developing L2 learners with advanced orthographic knowledge in an opaque orthography may ACCOMMODATE their cognitive processing strategies, resulting not only in improved VAS but also in shifts in their cognitive attentional priors, affecting how they approach multi-letter array processing. Indeed, our analyses support the hypothesis that acquiring a nonnative opaque orthography may alter participants' visuospatial sensitivity to orthography-specific statistical regularities. Participants with dyslexia, instead, showed less attentional flexibility, along with a reduced – although not completely absent – effect of L2 orthographic proficiency on VAS skills. Indeed, higher L2 orthographic proficiency also improved dyslexic participants' performance in the VAS task, though less than typical readers. One possible explanation is that VAS is less prone to crosslinguistic modulations in dyslexia due to a deficit at the visual processing level. An alternative explanation is that higher reading proficiency levels in English must be reached to observe VAS modulations in this group. However, automatizing reading skills in English may be challenging for readers with dyslexia, due to its phonologically demanding nature. Thus, it is also possible that cumulative experience with other foreign less-opaque languages (e.g., French) could enhance VAS modulations in dyslexia. In summary, this study demonstrated that the experience with a late-acquired opaque orthography can influence how visual attention resources are distributed during multi-letter array processing in late biliterates with a transparent language, underscoring the positive impact of biliteracy on reading-related cognitive abilities in both typical and clinical populations of L2 learners.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S1366728925000124.

Data availability. The data that support the findings of this study are openly available in OSF at https://osf.io/8hdcr/?view_only=23752aaaa0de41dcbba05d5174e4bd83

Acknowledgments. We would like to thank Maria Luisa Lorusso and Daniela Traficante as well as two anonymous reviewers for their comments on previous versions of the papers and the ideas presented herein. We wish to express our gratitude to the teachers and students of the Liceo Europeo di Arconate, Liceo Claudio Cavalleri and Istituto Gregorio Mendel (Milan, Italy) for their support and for granting permission to collect the data.

This research was supported and funded by the Landesgraduiertenförderungsgesetz (LGFG) scholarship from the University of Konstanz, awarded to I.V., and by the Basque Government through the BERC 2022–2025 program and funded by the Spanish State Research Agency through BCBL Severo Ochoa excellence accreditation CEX2020-001010/AEI/10.13039/501100011033 and PRP-PID2022-136989OB-I00 to M.L.

Competing interest. The authors declare none.

Ethical statement. All protocols in this study were approved by the Ethic Committee of the University of Konstanz in compliance with the specific regulations of the university for ethical experimentation and data storage, with the Declaration of Helsinki in its current version as developed by the World Medical Association and with relevant national and international laws and regulations.

References

Ans, B., **Carbonnel, S.**, & **Valdois, S**. (1998). A connectionist multiple-trace memory model for polysyllabic word reading. *Psychological Review*, **105**(4), 678–723. https://doi.org/10.1037/0033-295x.105.4.678-723

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. https://doi.org/10.1007/s11145-017-9799-0

Antzaka, A., **Acha, J.**, **Carreiras, M.**, & **Lallier, M**. (2019). Does the visual attention span play a role in the morphological processing of orthographic stimuli? *Quarterly Journal of Experimental Psychology*, **72**(7), 1704–1716. https://doi.org/10.1177/1747021818806470

Anwyl-Irvine, A. L., **Massonnié, J.**, **Flitton, A.**, **Kirkham, N.**, & **Evershed, J. K**. (2020). Gorilla in our midst: An online behavioral experiment builder. *Behavior Research Methods*, **52**(1), 388–407. https://doi.org/10.3758/s13428-019-01237-x

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 skilled adult readers [Original Research]. *Frontiers in Psychology*, **7**. https://doi.org/10.3389/fpsyg.2016.00307

Awadh, F. H. R., **Zoubrinetzky, R.**, **Zaher, A.**, & **Valdois, S**. (2022). Visual attention span as a predictor of reading fluency and reading comprehension in Arabic. *Frontiers in Psychology*, **13**. https://doi.org/10.3389/fpsyg.2022.868530

Barr, D. J., **Levy, R.**, **Scheepers, C.**, & **Tily, H. J**. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, **68**(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., **Mächler, M.**, **Bolker, B.**, & **Walker, S**. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, **67**(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Borleffs, E., **Maassen, B. A. M.**, **Lyytinen, H.**, & **Zwarts, F**. (2017). Measuring orthographic transparency and morphological-syllabic complexity in alphabetic orthographies: A narrative review. *Reading and Writing: An Interdisciplinary Journal*, **30**(8), 1617–1638. https://doi.org/10.1007/s11145-017-9741-5

Borleffs, E., **Maassen, B. A. M.**, **Lyytinen, H.**, & **Zwarts, F**. (2019). Cracking the code: The impact of orthographic transparency and morphological-syllabic complexity on reading and developmental Dyslexia [Review]. *Frontiers in Psychology*, **9**. https://doi.org/10.3389/fpsyg.2018.02534

Bosse, M. L. (2015). Learning to read and spell: How children acquire word orthographic knowledge. *Child Development Perspectives*, **9**(4), 222–226. https://doi.org/10.1111/cdep.12133

Bosse, M. L., **Chaves, N.**, **Largy, P.**, & **Valdois, S**. (2015). Orthographic learning during reading: the role of whole-word visual processing. *Journal of Research in Reading*, **38**(2), 141–158. https://doi.org/10.1111/j.1467-9817.2012.01551.x

Bosse, M. L., & **Valdois, S**. (2009). Influence of the visual attention span on child reading performance: A cross-sectional study. *Journal of Research in Reading*, **32**(2), 230–253. https://doi.org/10.1111/j.1467-9817.2008.01387.x

Bosse, M. L., **Tainturier, M. J.**, & **Valdois, S**. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition*, **104**(2), 198–230. https://doi.org/10.1016/j.cognition.2006.05.009

Buetler, K., **de León Rodríguez, D.**, **Laganaro, M.**, **Müri, R.**, **Spierer, L.**, & **Annoni, J. M**. (2014). Language context modulates reading route: An electrical neuroimaging study [Original Research]. *Frontiers in Human Neuroscience*, **8**. https://doi.org/10.3389/fnhum.2014.00083

Coltheart, M. (2005). modeling reading: the dual-route approach. In M. J. Snowling, & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 6–23). Blackwell Publishing. https://doi.org/10.1002/9780470757642.ch1

Coltheart, M., **Rastle, K.**, **Perry, C.**, **Langdon, R.**, & **Ziegler, J**. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, **108**(1), 204–256. https://doi.org/10.1037/0033-295x.108.1.204

Cornoldi, C., **Pra Baldi, A.**, & **Giofrè, D**. (2017). *Prove MT Avanzate-3-Clinica. La valutazione delle abilità di Lettura, Comprensione, Scrittura e Matematica per il biennio della Scuola Secondaria di II Grado*. Erikson.

Cornoldi, C., & **Candela, M**. (2015). *Prove di lettura e scrittura MT-16-19*. Erickson. https://www.erickson.it/it/prove-di-lettura-e-scrittura-mt1619

Cornoldi, C., **Rivella, C.**, **Montesano, L.**, & **Toffalini, E**. (2022). Difficulties of young adults with dyslexia in reading and writing numbers. *Journal of Learning Disabilities*, **55**(4), 338–348. https://doi.org/10.1177/00222194211037061

de León Rodríguez, D., **Buetler, K. A.**, **Eggenberger, N.**, **Preisig, B. C.**, **Schumacher, R.**, **Laganaro, M.**, **Nyffeler, T.**, **Annoni, J.-M.**, & **Müri, R. M**. (2016). The modulation of reading strategies by language opacity in early bilinguals: An eye movement study. *Bilingualism: Language and Cognition*, **19**(3), 567–577. https://doi.org/10.1017/S1366728915000310

Egan, C., **Oppenheim, G. M.**, **Saville, C.**, **Moll, K.**, & **Jones, M. W**. (2019). Bilinguals apply language-specific grain sizes during sentence reading. *Cognition*, **193**, 104018. https://doi.org/10.1016/j.cognition.2019.104018

Gavril, L., **Roşan, A.**, & **Szamosközi, Ş**. (2021). The role of visual-spatial attention in reading development: A meta-analysis. *Cognitive Neuropsychology*, **38**(6), 387–407. https://doi.org/10.1080/02643294.2022.2043839

Germano, G. D., **Reilhac, C.**, **Capellini, S. A.**, & **Valdois, S**. (2014). The phonological and visual basis of developmental dyslexia in Brazilian Portuguese reading children [Original Research]. *Frontiers in Psychology*, **5**. https://doi.org/10.3389/fpsyg.2014.01169

Goswami, U. (2015). Visual attention span deficits and assessing causality in developmental dyslexia. *Nature Review Neuroscience*, **16**(4), 225. https://doi.org/10.1038/nrn3836-c2

Grainger, J., **Dufau, S.**, & **Ziegler, J. C**. (2016). A vision of reading. *Trends in Cognitive Sciences*, **20**(3), 171–179. https://doi.org/10.1016/j.tics.2015.12.008

Huang, C., **Lorusso, M. L.**, **Luo, Z.**, & **Zhao, J**. (2019). Developmental differences in the relationship between visual attention span and Chinese reading fluency [Original Research]. *Frontiers in Psychology*, **10**. https://doi.org/10.3389/fpsyg.2019.02450

Iniesta, A., **Bajo, M. T.**, **Rivera, M.**, & **Paolieri, D**. (2023). Transfer effects from language processing to visual attention dynamics: The impact of orthographic transparency. *British Journal of Psychology*, **114**(1), 86–111. https://doi.org/10.1111/bjop.12598

Katz, L., & **Frost, R**. (1992). The reading process is different for different orthographies: The orthographic depth hypothesis. In R. Frost, & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). North-Holland. https://doi.org/10.1016/S0166-4115(08)62789-2

Lallier, M., **Abu Mallouh, R.**, **Mohammed, A. M.**, **Khalifa, B.**, **Perea, M.**, & **Carreiras, M**. (2018a). Does the visual attention span play a role in reading in Arabic? *Scientific Studies of Reading*, **22**(2), 181–190. https://doi.org/10.1080/10888438.2017.1421958

Lallier, M., **Acha, J.**, & **Carreiras, M**. (2016). Cross-linguistic interactions influence reading development in bilinguals: A comparison between early balanced French-Basque and Spanish-Basque bilingual children. *Developmental Science*, **19**(1), 76–89. https://doi.org/10.1111/desc.12290

Lallier, M., & **Carreiras, M**. (2018). Cross-linguistic transfer in bilinguals reading in two alphabetic orthographies: The grain size accommodation hypothesis. *Psychonomic Bulletin & Review*, **25**(1), 386–401. https://doi.org/10.3758/s13423-017-1273-0

Lallier, M., **Carreiras, M.**, **Tainturier, M. J.**, **Savill, N.**, & **Thierry, G**. (2013a). Orthographic transparency modulates the grain size of orthographic processing: behavioral and ERP evidence from bilingualism. *Brain Research*, **1505**, 47–60. https://doi.org/10.1016/j.brainres.2013.02.018

Lallier, M., **Donnadieu, S.**, & **Valdois, S**. (2013b). Investigating the role of visual and auditory search in reading and developmental dyslexia. *Frontiers in Human Neuroscience*, **7**, 597. https://doi.org/10.3389/fnhum.2013.00597

Lallier, M., **Donnadieu, S.**, & **Valdois, S**. (2013c). Developmental dyslexia: Exploring how much phonological and visual attention span disorders are linked to simultaneous auditory processing deficits. *Annals of Dyslexia*, **63**(2), 97–116. https://doi.org/10.1007/s11881-012-0074-4

Lallier, M., **Martin, C. D.**, **Acha, J.**, & **Carreiras, M**. (2021). Cross-linguistic transfer in bilingual reading is item specific. *Bilingualism: Language and Cognition*, **24**(5), 891–901. https://doi.org/10.1017/S1366728921000183

Lallier, M., **Thierry, G.**, **Barr, P.**, **Carreiras, M.**, & **Tainturier, M. J**. (2018b). Learning to read bilingually modulates the manifestations of dyslexia in adults. *Scientific Studies of Reading*, **22**, 1–15. https://doi.org/10.1080/10888438.2018.1447942

Lallier, M., **Valdois, S.**, **Lassus-Sangosse, D.**, **Prado, C.**, & **Kandel, S**. (2014). Impact of orthographic transparency on typical and atypical reading development: Evidence in French-Spanish bilingual children. *Research in Developmental Disabilities*, **35** (5), 1177–1190. https://doi.org/10.1016/j.ridd.2014.01.021

Lemhöfer, K., & **Broersma, M**. (2012). Introducing LexTALE: A quick and valid Lexical Test for Advanced Learners of English. *Behavior Research Methods*, **44**(2), 325–343. https://doi.org/10.3758/s13428-011-0146-0

Lenth, R. (2024). emmeans: Estimated marginal means, aka least-squares means. R package version 1.10.0, https://CRAN.R-project.org/package=emmeans

Liesefeld, H. R., & **Janczyk, M**. (2019). Combining speed and accuracy to control for speed-accuracy trade-offs(?). *Behavior Research Methods*, **51**(1), 40–60. https://doi.org/10.3758/s13428-018-1076-x

Liu, J., **Ren, X.**, **Wang, Y.**, & **Zhao, J**. (2023). Visual attention span capacity in developmental dyslexia: A meta-analysis. *Research in Developmental Disabilities*, **135**, 104465. https://doi.org/10.1016/j.ridd.2023.104465

Lobier, M., **Dubois, M.**, & **Valdois, S**. (2013). The role of visual processing speed in reading speed development. *PLoS One*, **8**(4), e58097. https://doi.org/10.1371/journal.pone.0058097

Lobier, M., **Zoubrinetzky, R.**, & **Valdois, S**. (2012). The visual attention span deficit in dyslexia is visual and not verbal. *Cortex*, **48**(6), 768–773. https://doi.org/10.1016/j.cortex.2011.09.003

Lorusso, M. L., & **Toraldo, A**. (2023). Revisiting multifactor models of dyslexia: Do they fit empirical data and what are their implications for intervention? *Brain Sciences*, **13**(2), 328. https://www.mdpi.com/2076-3425/13/2/328

Marinelli, C. V., **Romani, C.**, **Burani, C.**, **McGowan, V. A.**, & **Zoccolotti, P**. (2016). Costs and benefits of orthographic inconsistency in reading: Evidence from a cross-linguistic comparison. *PLoS One*, **11**(6), e0157457. https://doi.org/10.1371/journal.pone.0157457

Martelli, M., **Di Filippo, G.**, **Spinelli, D.**, & **Zoccolotti, P**. (2009). Crowding, reading, and developmental dyslexia. *Journal of Vision*, **9**(4), 1–18. https://doi.org/10.1167/9.4.14

Monaco, M., **Costa, A.**, **Caltagirone, C.**, & **Carlesimo, G. A**. (2013). Forward and backward span for verbal and visuo-spatial data: Standardization and normative data from an Italian adult population. *Neurological Sciences*, **34**(5), 749–754. https://doi.org/10.1007/s10072-012-1130-x

Montesano, L., **Valenti, A.**, & **Cornoldi, C**. (2020). *LSC-SUA prove di lettura, comprensione del testo, scrittura e calcolo. Batteria per la valutazione dei DSA e altri disturbi in studenti universitari e adulti.* Erikson.

Müller, H. J., & **Findlay, J. M**. (1987). Sensitivity and criterion effects in the spatial cuing of visual attention. *Perception & Psychophysics*, **42**(4), 383–399. https://doi.org/10.3758/BF03203097

Olson, R., **Forsberg, H.**, **Wise, B.**, & **Rack, J**. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement issues* (pp. 243–277). Paul H. Brookes Publishing Co.

Perfetti, C., & **Harris, L**. (2019). Developmental Dyslexia in English. In L. Verhoeven, C. Perfetti, & K. Pugh (Eds.), *Developmental Dyslexia Across Languages and Writing Systems* (pp. 25–49). Cambridge University Press.

Perry, C., & **Long, H**. (2022). What is going on with visual attention in reading and dyslexia? A critical review of recent studies. *Brain Sciences*, **12**(1), 87. https://www.mdpi.com/2076-3425/12/1/87

Perry, C., **Zorzi, M.**, & **Ziegler, J. C**. (2019). Understanding dyslexia through personalized large-scale computational models. *Psychological Science*, **30**(3), 386–395. https://doi.org/10.1177/0956797618823540

Ramus, F., **Rosen, S.**, **Dakin, S. C.**, **Day, B. L.**, **Castellote, J. M.**, **White, S.**, & **Frith, U**. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. *Brain*, **126**(4), 841–865. https://doi.org/10.1093/brain/awg076

Ripamonti, E., **Luzzatti, C.**, **Zoccolotti, P.**, & **Traficante, D**. (2018). Word and pseudoword superiority effects: Evidence from a shallow orthography language. *Quarterly Journal of Experimental Psychology*, **71**(9), 1911–1920. https://doi.org/10.1080/17470218.2017.1363791

Scaltritti, M., & **Balota, D. A**. (2013). Are all letters really processed equally and in parallel? Further evidence of a robust first letter advantage. *Acta Psychologica*, **144**(2), 397–410. https://doi.org/10.1016/j.actpsy.2013.07.018

Schmalz, X., **Marinus, E.**, **Coltheart, M.**, & **Castles, A**. (2015). Getting to the bottom of orthographic depth. *Psychonomic Bulletin & Review*, **22**, 1614–1629. https://doi.org/10.3758/s13423-015-0835-2

Seymour, P. H., **Aro, M.**, & **Erskine, J. M**. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, **94**, 143–174. https://doi.org/10.1348/000712603321661859

Snowling, M. J. (2001). From language to reading and dyslexia. *Dyslexia*, **7**(1), 37–46. https://doi.org/10.1002/dys.185

Spinelli, D., **De Luca, M.**, **Judica, A.**, & **Zoccolotti, P**. (2002). Crowding effects on word identification in developmental dyslexia. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, **38**(2), 179–200. https://doi.org/10.1016/s0010-9452(08)70649-x

Valdois, S. (2022). The visual-attention span deficit in developmental dyslexia: Review of evidence for a visual-attention-based deficit. *Dyslexia*, **28**(4), 397–415. https://doi.org/10.1002/dys.1724

Valdois, S., **Bosse, M. L.**, & **Tainturier, M. J**. (2004). The cognitive deficits responsible for developmental dyslexia: Review of evidence for a selective visual attentional disorder. *Dyslexia*, **10**(4), 339–363. https://doi.org/10.1002/dys.284

Valdois, S., **Lassus-Sangosse, D.**, & **Lobier, M**. (2012). Impaired letter-string processing in developmental dyslexia: What visual-to-phonology code mapping disorder? *Dyslexia*, **18**, 77–93. https://doi.org/10.1002/dys.1437

Valdois, S., **Roulin, J. L.**, & **Bosse, M. L**. (2019). Visual attention modulates reading acquisition. *Vision Research*, **165**, 152–161. https://doi.org/10.1016/j.visres.2019.10.011

van den Boer, M., **van Bergen, E.**, & **de Jong, P. F**. (2015). The specific relation of visual attention span with reading and spelling in Dutch. *Learning and Individual Differences*, **39**, 141–149. https://doi.org/10.1016/j.lindif.2015.03.017

Vellutino, F. R., **Fletcher, J. M.**, **Snowling, M. J.**, & **Scanlon, D. M**. (2004). Specific reading disability (dyslexia): what have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, **45**(1), 2–40. https://doi.org/10.1046/j.0021-9630.2003.00305.x

Xu, Z., **Theeuwes, J.**, & **Los, S. A**. (2023). Statistical learning of spatiotemporal regularities dynamically guides visual attention across space. *Attention, Perception, & Psychophysics*, **85**(4), 1054–1072. https://doi.org/10.3758/s13414-022-02573-5

Ziegler, J. C., **Bertrand, D.**, **Tóth, D.**, **Csépe, V.**, **Reis, A.**, **Faísca, L.**, **Saine, N.**, **Lyytinen, H.**, **Vaessen, A.**, & **Blomert, L**. (2010). Orthographic depth and its impact on universal predictors of reading: A cross-language investigation. *Psychological Science*, **21**(4), 551–559. https://doi.org/10.1177/0956797610363406

Ziegler, J. C., & **Goswami, U**. (2005). Reading acquisition, developmental dyslexia, and skilled reading across Languages: A psycholinguistic grain size theory. *Psychological Bulletin*, **131**(1), 3–29. https://doi.org/10.1037/0033-2909.131.1.3

Ziegler, J. C., **Perry, C.**, **Jacobs, A. M.**, & **Braun, M**. (2001). Identical words are read differently in different languages. *Psychological Science*, **12**(5), 379–384. https://doi.org/10.1111/1467-9280.00370

Ziegler, J. C., **Perry, C.**, & **Zorzi, M**. (2020). Learning to read and dyslexia: From theory to intervention through personalized computational models. *Current Directions in Psychological Science*, **29**(3), 293–300. https://doi.org/10.1177/0963721420915873