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Visual multi-element processing as a pre-reading predictor of decoding skill

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ABSTRACT

A lack of longitudinal studies impedes the understanding of whether visual processing skills significantly influence reading performance. The present study assessed if multi-element processing (MEP), a visual processing task comprising only non-verbal stimuli, was predominantly related with decoding or sight-word reading. One hundred Spanish pre-reading children were evaluated on their MEP, naming speed (RAN), phonemic awareness (PA), letter knowledge (LK) and IQ. Early reading level was measured in first grade. In third grade, four reading lists consisting of short and long, high- and low-frequency words were administered. Results from path analyses revealed that, after controlling for RAN, PA, LK, IQ and early reading level, MEP was a significant predictor of the reading of long low-frequency words only. This result suggests that, in the transparent Spanish orthography, pre-reading MEP is significantly linked to future decoding skill. This is the first study to provide empirical evidence that pre-reading MEP predicts future reading.

Introduction

Research in the field of literacy acquisition has firmly established that certain cognitive abilities, such as phonemic awareness (PA) and naming speed, are crucially involved in the process of learning to read (see Bowey, 2005; Kirby, Roth, Desrochers, & Lai, 2008 for reviews). However, the potential importance of another cognitive ability, visual processing skill (VPS), has been less explored. Although a link between visual skill and reading has been suggested for several decades (e.g., Cairns & Steward, 1970; Lovegrove, Martin, & Slaghuis, 1986; Mason & Katz, 1976), in recent years there has been a growing recognition of this possibility (Lallier, Valdois, Lassus-Sangosse, Prado, & Kandel, 2014; Lobier, Dubois, & Valdois, 2013; van den Boer & de Jong, 2015). However, whether visual skill is causally related to reading remains an open question (see Goswami, 2015a; Lobier & Valdois, 2015 for an interesting discussion on the topic) given that many studies have failed to find a significant relationship between the two (e.g., Shapiro, Carroll, & Solity, 2013; Vellutino, Scanlon, Small, & Tanzman, 1991).

Visual processing skills comprise several abilities which have been claimed to be associated with reading development and dyslexia (for reviews on the topic see Gori & Facoetti, 2015; Rayner, 2009; Vidyasagar & Pammer, 2010). Visual skills such as visual searching ability (e.g., Jones, Branigan, & Kelly, 2008), sensitivity to coherent motion (e.g., Witton et al., 1998), visual scanning ability (e.g., Kuperman, Van Dyke, & Henry, 2016) or visuo-spatial attention (e.g., Facoetti et al., 2010), have all been linked to reading performance. In general, MEP tasks assess the accuracy with which the participant can recognize or recall the identity or position of symbols previously presented in a multi-element array (e.g., Hawelka &

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Wimmer, 2005; Jones et al., 2008; Pammer, Lavis, Hansen, & Cornelissen, 2004). For instance, visual attention span – which according to Bosse and Valdois (2009) is defined as the number of distinct visual elements which can be simultaneously processed at a glance in a multi-element array – has been reported to contribute to reading performance in normally developing children, beyond other established predictors such as IQ, vocabulary, and PA (Bosse & Valdois, 2009; van den Boer, de Jong, & Haentjens-van Meeteren, 2013). However, one critical, yet unanswered question regarding the VPS-reading relationship is whether visual skill (and MEP in particular) is specifically related to analytical decoding of novel words, whether it is predominantly involved in global recognition of known words, or both.

Unknown words are decoded, known words are recognized by sight

Numerous reading models from different areas of literacy studies (e.g., Ans, Carbonnel, & Valdois, 1998; Ehri, 2005; Share, 2008) describe how readers use two critical procedures to decipher text. Although these two procedures have been assigned many labels (e.g., 'serial *vs.* parallel' or 'analytic *vs.* global'), for this study we will use the terms decoding and sight-word reading. As postulated by various developmental reading models (e.g., Backman, Bruck, Hebert, & Seidenberg, 1984; Ehri, 2005; Share, 2008), as well as several models of skilled reading (e.g., Ans et al., 1998; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Forster & Chambers, 1973; LaBerge & Samuels, 1974; Perry, Ziegler, & Zorzi, 2007; Ziegler, Perry, & Zorzi, 2014), orthographic familiarity is one key element which will determine how print will be processed.

According to these models, in order to process novel or unfamiliar words, the reader will use a slow sub-lexical decoding strategy which relies on graphemic parsing. Graphemic parsing can best be conceived as a process that operates via an attentional window which shifts from left to right parsing the letter string into graphemes in a serial fashion (e.g., Perry et al., 2007). These graphemes are then sequentially converted into their phonological counterparts and subsequently assembled into spoken words. In contrast, a different procedure is implemented when a known or familiar word is encountered. If the printed letter-string matches an entry in the orthographic lexicon the word will be automatically recognized as a whole unit. In this case the phonological representation associated with that word will be instantly activated via rapid direct-retrieval mechanisms. It should be noted that, according to most models of skilled reading (e.g., Dual Route Cascaded [DRC], Coltheart et al., 2001; Multiple-Trace Memory [MTM], Ans et al., 1998), all stimuli are processed through both reading procedures. However, familiar words tend to be processed more accurately and faster through sight-word reading while unfamiliar words cannot be accurately read by sight and therefore end up being decoded.

Of note, according to Grainger and colleagues (Grainger, Dufau, & Ziegler, 2016; Grainger & Ziegler, 2011), these two reading procedures require a different level of precision with respect to letter-position encoding. The sight-word reading strategy/procedure initially makes use of the most visible letters that best constrain word identity. Letter combination detectors allow the reader to code in parallel for approximate within-word letter position as a means to provide rapid bottom-up activation of familiar whole-word representations (Grainger & Ziegler, 2011). The use of coarse-grained features (not necessarily contiguous letter combinations) gives preference to speed over accuracy (Grainger et al., 2016). Processing through serial analytical decoding, on the other hand, requires more precise position-coded letter identities, which gives preference to accuracy over speed in generating sound from print (Grainger & Ziegler, 2011; Grainger et al., 2016). In support of this perspective, Ziegler et al.'s (2014) connectionist dual process computational model can simulate how letter-position encoding errors affect unfamiliar word reading.

In agreement with the notion that familiarity determines reading procedure, familiarity-related psycholinguistic factors such as 'word-frequency' or 'age-of-acquisition' have been reported to exert the strongest effects on reading speed (Italian: Barca, Burani, & Arduino, 2002; French: Bonin, Barry, Méot, & Chalard, 2004; Spanish: Cuetos & Barbón, 2006; Japanese Kanji: Yamazaki, Ellis, Morrison, & Ralph, 1997). The word frequency effect, whereby high frequency words are processed faster than matched low frequency words, is evidence that familiar words are processed through rapid sight-word reading, while unfamiliar words are slowly decoded (Share, 1995; Weekes, 1997).

A different effect, namely the length effect, is another marker of reading procedure. The length effect reflects how shorter words are processed faster than longer words (English: Weekes, 1997; Dutch: Marinus & de Jong, 2010; German: Ziegler, Perry, Jacobs, & Braun, 2001; Spanish: Cuetos & Barbón, 2006). Of relevance, it tends to be larger for unfamiliar words, which must be decoded through a length-sensitive sequential mechanism, than for familiar words, which are instantly recognized a in parallel manner (Weekes, 1997; Ziegler et al., 2001). Thus, this word-length by word-familiarity interaction on naming latencies is further evidence of sight-word reading for familiar words and serial decoding for unfamiliar words. In this way, word-frequency and -length are useful tools to determine which reading strategy is being used – decoding or sight word reading.

What is the role played by visual multi-element processing in reading?

The main research question of this study is whether visual skill, measured by means of visual MEP, is specifically related (1) to decoding, (2) to sight-word reading or (3) to both. Firstly, in support of the idea that MEP is only involved in decoding, Jones et al. (2008) and Pammer et al. (2004) found that performance on MEP was significantly correlated with reading accuracy of unfamiliar words and with passage reading accuracy respectively. According to Facoetti et al. (2006), focused visual attention is important for graphemic parsing during unfamiliar-word reading. As suggested in the connectionist dual process (CDP+) model

(Perry et al., 2007), the understanding is that serial allocation of focused spatial attention must be sequentially shifted across the letter string during the analytical decoding of an unfamiliar word. In line with this view, several studies have reported a significant relationship between visuo-spatial attention and unfamiliar word reading (Auclair & Siéroff, 2002; Facoetti et al., 2006, 2010; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Kinsey, Rose, Hansen, Richardson, & Stein, 2004).

If serial allocation of attention across the letter string is specifically relevant to decoding, it should manifest through a significant contribution by MEP to unfamiliar word reading. This MEP contribution to unfamiliar word reading should apply to short- and long- unfamiliar words, as both require the reader's attention to be shifted across the letter string. Furthermore, if as proposed by Grainger et al. (2016), sight-word reading relies on flexible, relatively imprecise orthographic representations, while decoding relies on precise position-encoded letter identities, MEP accuracy might be more significantly related to the latter, especially if measured through symbol-position encoding.

A second possibility is that MEP might be involved in both decoding of unfamiliar words and sight-word reading of familiar words. The Multiple-Trace Memory (MTM) connectionist model (Ans et al., 1998) posits that reading is accomplished via two processes: a global (sight-word reading) approach which is generally applied to familiar words, and an analytic (decoding) procedure which is more useful for unfamiliar words. Whereas the global processing requires a larger visual attention span which extends over the whole letter string, the analytic procedure requires visual attention to be focused successively on smaller orthographic units, such as syllables or letters, resulting in length effects (van den Boer et al., 2013). In support of this view, there is evidence that visual attention span is both related to serial processing during unfamiliar word reading, as well as to sight-word reading of familiar words (e.g., Bosse & Valdois, 2009; Lallier et al., 2014; van den Boer et al., 2013). Nevertheless, further studies are required to determine whether visual attention is distributed over the letter string in the fashion described by the MTM model (see the discussion for further reflection on this topic).

The third possibility is that MEP might be involved exclusively in sight-word reading, but not in decoding, given that the former, like MEP performance, requires the reader to encode and recognize the whole orthographic representation of the string. However, we are unaware of any studies which have obtained results supporting this possibility. Furthermore, the only VPS-reading study, to our knowledge, conducted with a Spanish-speaking sample also found MEP to significantly correlate to both familiar and unfamiliar word reading (Lallier et al., 2014).

If the number of visual elements which can be processed in a multi-element array is relevant to reading performance, it follows that short words will require less multi-element processing demand than longer words. In support of this perspective, Hawelka and Wimmer (2005) found that readers with dyslexia exhibited poorer performance than controls for recognition of four- and six-digit strings, but not for two-digit strings. This result suggests that low ability in visual multi-element processing for long symbol-strings may contribute to reading deficits. Furthermore, in line with the view that a reader's maximum size of the visuo-attentional window determines reading speed (Ans et al., 1998), fast-reading children (Häikiö, Bertram, Hyönä, & Niemi, 2009) and adults (Rayner, Slattery, & Bélanger, 2010) have been found to exhibit larger perceptual spans than their slow-reading peers. Moreover, performance on visual tasks which require the participant to recognize/identify items within multi-element arrays has been reported to predict reading speed (Kwon, Legge, & Dubbels, 2007; Lobier et al., 2013) independently of IQ, PA (Bosse & Valdois, 2009) and RAN (van den Boer et al., 2013), thus supporting the idea that MEP should be more strongly related to the reading speed of long- rather than short-words.

Methodological issues

Two methodological issues of paramount importance have often been overlooked in studies assessing the link between MEP and reading. Firstly, many of the studies which have found a link between MEP and reading have relied on tasks in which the items are comprised of letters or for which the response is provided verbally (e.g., Bosse, Tainturier, & Valdois, 2007; Kwon et al., 2007; Valdois, Bosse, & Tainturier, 2004). This is problematic because some studies have found a significant link between MEP and reading *only* when the corresponding visual task required a verbal response (Hawelka & Wimmer, 2008) or contained verbal material (Collis, Kohnen, & Kinoshita, 2013; Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). These latter findings are difficult to reconcile with the notion that pure visual skills play an independent role in reading, suggesting that visual skill tasks which involve verbal material actually measure symbol-sound mapping (Ziegler et al., 2010). However, other studies have found that MEP deficits also extend to visual tasks involving no phonological component (Jones et al., 2008; Lobier, Zoubrinetzky, & Valdois, 2012). Pammer et al. (2004) along with Jones et al. (2008) found that sensitivity to the spatial sequence of non-nameable symbol strings significantly correlated with reading. This conflicting evidence, together with the fact that letter-knowledge itself is a well-established early predictor of reading skill (Bowey, 2005), indicates that letters are non-adequate stimuli when attempting to assess whether pure visual skill is significantly related to reading (Goswami, 2015a, 2015b).

The second methodological issue relates to the reciprocal nature of the relationship between visual skill and reading. In the same way as visual skill has been reported to influence reading performance (e.g., Bosse et al., 2007), reading practice has also been shown to account for a significant improvement in visual skill (Dehaene et al., 2010; McBride-Chang et al., 2011; Perfetti, Cao, & Booth, 2013). This reciprocal relationship is similar to the one held by phonemic awareness and reading development (e.g., Bentin & Leshem, 1993; Hogan, Catts, & Little, 2005) and can easily lead to a misinterpretation of the VPS-reading relationship. Inferring the direction of causality can be problematic when a significant concurrent correlation is found between a cognitive ability and reading in a sample of individuals who already have several years of reading experience. For instance, the reported link between MEP and reading (Jones et al., 2008; Lobier et al., 2012; Pammer et al., 2004) could be predominantly accounted for by the influence that reading practice exerts on visual skill.

Furthermore, part of the uncertainty regarding the role that visual skill plays in reading (e.g., decoding vs. sight-word reading) might be due to the fact that most studies on this subject have focused on samples of children who have at least two years of reading experience (e.g., Bosse et al., 2007; Lobier et al., 2013; Valdois et al., 2006; van den Boer & de Jong, 2015). In such samples, the observed correlation between visual skill and sight-word reading, as opposed to decoding, may potentially arise from early reading practice simultaneously improving both visual ability and sight-word reading. These findings raise the matter of testing chronology, and suggest that a study which aims to explore whether visual skill causally influences reading, should measure visual skill before the onset of literacy instruction (Goswami, 2015a; Lobier & Valdois, 2015). Ideally such a study should confirm there are no early readers in the sample.

Moreover, even when studies examining the contribution made by visual skill to reading have assessed pre-reading levels of visual skill, contradicting results have been found. For instance, Franceschini, Gori, Ruffino, Pedrolli, and Facoetti (2012) found individual differences in visual search and spatial cue facilitation tasks, measured in kindergarten, to predict both familiar and unfamiliar word reading measured in Grades 1 and 2. In contrast, Plaza and Cohen (2007) along with Shapiro et al. (2013) failed to find a relationship between pre-reading visual search skills and reading of familiar or unfamiliar words measured in Grade 1. Importantly, no study to-date has examined the longitudinal contribution of pre-reading visual MEP ability (using either letters or using symbols) to future reading.

This study

The purpose of this study was to examine the potential contribution by early levels of visual multi-element processing (MEP) to each of the two most important reading procedures: decoding and sight-word reading. Assuming that unfamiliar words would be decoded, whilst highly familiar words would be automatically recognized as a whole (Ans et al., 1998; Ehri, 2005; Share, 2008), manipulation of word-frequency and word-length was carried out to explore the relationship between visual skill and reading. Furthermore, as the precise role played by visual processing skills (VPS) might be mediated by the ability to accurately process wide multi-element arrays, the word length manipulation was a useful tool in order to study this possibility. Our approach was to examine the specific contribution made by pre-reading visual multi-element processing to the reading of long and short, high- and low-frequency words measured in Grade 3.

We chose visual multi-element processing (MEP), as opposed to other visual skill tasks such as visual searching ability or sensitivity to coherent motion, because MEP is a more reading-like visual skill task. If visual skill is necessary for both decoding and sight-word reading, MEP is expected to contribute to the reading of familiar and unfamiliar words. If in contrast, sublexical decoding is specifically influenced by visual skills, a stronger contribution by MEP to unfamiliar rather than to familiar words will be revealed. When attempting to examine the effect of familiarity, manipulating word-frequency (high- vs. low-frequency words) rather than lexicality (words vs. non-words) avoids the influence of uncontrolled factors to which non-word creation is susceptible (e.g., bigram frequencies or syllable-position frequencies which might be non-representative of the Spanish orthography). Therefore, for this study we chose to manipulate word familiarity via word frequency. Furthermore, if MEP determines reading speed performance, word-length should mediate the MEP-reading relationship. Thus, we included both short and long stimuli in the study.

Numerous studies have documented the robust predictive power of naming speed, as measured through the RAN task, to future reading skill in diverse languages (e.g., English: Kirby, Parrila, & Pfeiffer, 2003; Norwegian: Lervåg, Bråten, & Hulme, 2009; German: Moll, Fussenegger, Willburger, & Landerl, 2009). Studies which have measured the effect of naming speed on reading in Spanish have also found significant relationships (e.g., Rodríguez, van den Boer, Jiménez, & de Jong, 2015; Suárez-Coalla, García-De-Castro, & Cuetos, 2013). Furthermore, RAN has been found to contribute similarly to unfamiliar compared to familiar word reading (Dutch: van den Boer et al., 2013; Danish: Poulsen & Elbro, 2013; German: Moll et al., 2009). Consequently, although the purpose of the present study was to examine the VPS-reading relationship, given that RAN's relationship to reading has been firmly established, it was essential to include RAN in the study as a control measure.

Likewise, it is widely accepted that phonological skills are intricately linked with the process of learning to read. However, results from longitudinal studies conducted in transparent orthographies have consistently found that the contribution by early-PA to reading is only important during the first one or two years of schooling, but not beyond that period (Norwegian: Lervåg et al., 2009; Dutch: De Jong & van der Leij, 1999; German: Landerl & Wimmer, 2000, 2008; Turkish: Öney & Durgunoğlu, 1997; Finnish: Leppänen, Niemi, Aunola, & Nurmi, 2006; Spanish: Defior, 2008). This evidence suggests that in Spanish, a highly regular orthography, pre-reading PA is not likely to have a significant influence on reading after the earliest phases of development. Nevertheless, given PA's acknowledged contribution to reading development, it was also imperative to include it in the study as a control variable.

Verbal IQ, non-verbal IQ and early letter knowledge (LK) were also be controlled, as was Grade 1 reading performance to guarantee that any contribution by visual skill to Grade 3 reading is direct and not mediated by prior reading level. Finally, to avoid the possibility that the cognitive abilities of interest may have already been transformed by reading practice, all cognitive variables were measured before formal reading instruction had commenced and early readers were excluded from the sample. To our knowledge, this is the first longitudinal study which has examined the effects of pre-reading visual multi-element processing on future reading.

Methodology

Participants

All participants were monolingual Spanish speakers and had parental and school consent to participate. Children who were unable to complete the tasks due to speech, cognitive, and/or hearing disability were excluded from the study. All children had normal or corrected to normal vision. The initial assessment was undertaken in the middle of the kindergarten year. A total of 188 children (85 girls, 103 boys) commenced the study at kindergarten, but due to dropouts and absenteeism during the subsequent years, only 158 children (70 girls, 88 boys) completed all tasks at all time-points. In order to ensure that the sample was uniquely composed of children who were pre-readers at the onset of the study, all early readers were excluded from the sample (described below). The 100 children (42 girls, 58 boys) retained for the study had a mean age of 5;6 (*SD* = 3.6 months, range 5;1–6;1).

Design and procedure

The predictor cognitive abilities of interest, along with the control variables, were assessed in mid-kindergarten (February), nine months before the commencement of formal literacy instruction. Formal literacy instruction, which begins in Grade 1 in the Spanish curriculum, is taught by means of the phonics method. However, children are often introduced to some letters during kindergarten. In Spain the school year runs from September to June and early reading level was measured in November of Grade 1. In Grade 3, three years and three months after the cognitive abilities were measured, reading performance was assessed by means of four reading lists varying in word familiarity and word length.

Test and materials

All children were tested individually. All testing was done at their schools and the tasks were administered by trained experimenters. Five cognitive constructs (verbal and non-verbal IQ, PA, RAN and MEP), together with LK, were assessed in kindergarten and used to predict later reading skill. In all tasks children first saw a number of demonstration items and/or completed a number of practice items to ensure that they understood what was required of them.

General intelligence (kindergarten)

Verbal and non-verbal skills were evaluated as control variables. They were assessed using the Vocabulary and Block Design subtests taken from the Spanish version of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) for children (Wechsler, 2001).

Letter knowledge (kindergarten)

The 27 letters in the Spanish alphabet, as well as the two digraphs (*ch* and *ll*), were presented individually on separate cards. The children were first asked for the sound of each letter, or digraph, and then for the name. This same procedure was carried out twice: first with upper and then lowercase versions of the letters. One point was given for every correct response. Accuracy scores for the different letters names and sounds correctly provided by the child (uppercase and lowercase) were aggregated to produce the letter knowledge estimates.

Phonological awareness (kindergarten)

The phonological awareness variable which was used for all subsequent correlational and path analyses was computed by averaging the *z*-scores of the following two tasks.

Phoneme blending. This task required children to blend spoken phonemic segments into real, high frequency words. 10 mono- and bi-syllabic test items with increasingly complex syllable structure were administered. Partial points were awarded for correct phoneme recognition with a full point awarded for correctly pronouncing the whole target word.

Phoneme isolation. The task consisted of four blocks of eight non-word items. In the first two blocks, children were required to isolate and pronounce the initial phoneme whereas in the last two blocks the final phoneme was the focus of the task. The difficulty of the items increased from simple (CVC) to complex (CCVC) structures. Administration in each block was discontinued after four consecutive errors.

Naming speed (kindergarten)

Alphanumeric RAN (letters and digits) has been found to yield stronger correlations with literacy measures than non-alphanumeric RAN (objects and colors) in most studies which have compared the two (Lervåg et al., 2009; van den Bos, Zijlstra, & Lutje Spelberg, 2002). However, there are doubts about the methodological suitability of using a form of RAN which is partly based on letter knowledge, as letter knowledge itself has been widely recognized as a powerful predictor of early reading (Bowey, 2005). Because of the potential confound between letter knowledge and naming speed, non-alphanumeric forms of RAN were chosen for the present study, specifically objects and colors, for which Spanish versions were created (adapted from Denckla & Rudel, 1974). The RAN composite score was computed by averaging the *z*-scores of RAN Objects and RAN Colors.

RAN objects. Five items were repeated eight times, giving a total of forty stimuli, and these were displayed over five lines of an A-4 card. Children were asked to name the pictures sequentially and as fast as they could, starting in the upper left corner of the sheet and ending in the lower right.

Two trials were administered, with items arranged in a different, quasi-random order on each trial. The items consisted of drawings of a key [llave], a dog [perro], a table [mesa], an eye [ojo] and a lion [león]. The average of the two trials was used as the final score.

RAN Colors. The procedure and calculation for the RAN Colors task was identical to that of the RAN Objects task. The items consisted of the filled circles of the colors red [rojo], brown [marrón], green [verde], blue [azul] and black [negro].

Visual processing skills (kindergarten)

This visual multi-element processing task was based on a task used by Jones et al. (2008) and designed to measure the children's ability to encode the position of letter-like symbols within a string. Participants had to memorize the position of each item in the string and then select the correct string from a two-alternative forced-choice (2AFC). To guarantee that this task contained no phonological elements and measured pure visual processing ability, the task exclusively used non-linguistic symbols and required no verbal response. Hence, the stimuli consisted of a selection of Greek and Cyrillic characters which were chosen to minimize their visual similarity to the Latin letters which make up the Spanish alphabet. These symbols were not familiar to Spanish children within this study's age range, and thus can be considered non-nameable pseudo-letter symbols.

All stimuli consisted of horizontal sequences of adjacent symbols, forming word-like symbol strings. Stimuli were displayed in black on white background and were presented in upper-case 72-point Times New Roman font. The distance between the centers of each symbol was over 1 cm to avoid a crowding effect (Spinelli, De Luca, Judica, & Zoccolotti, 2002). Each trial consisted of a target string depicted on a memory card which was shown for 4 s and was immediately followed by a test card displaying two symbol-strings one above the other in a 2AFC paradigm. The exposure time for the target-string was chosen in order to allow the child enough time to observe the symbol string in the same manner that a novice reader would look at a word. Decoy strings consisted of the same symbols as the target string, but presented in a different order. Participants were instructed to decide which one of these two strings of symbols was presented in the preceding card by pointing to their chosen string. The number of symbols per string present in each trial progressively increased. Children were shown three blocks of items: four two-symbol, four three-symbol and four four-symbol strings. One point was awarded for each correct answer. Given the increasing difficulty of the stimuli, to reduce the possibility of adopting a guessing strategy the test was discontinued after three consecutive errors.

Reading measures

Familiarity word lists (Grade 3). Reading lists manipulating word familiarity and word length resulted in four main reading conditions: long high-frequency words (LHF), long low-frequency words (LLF), short high-frequency words (SHF), short low-frequency words (SLF). Each of these reading lists contained 25 words each (see Appendix A). The HF and LF lists contained words of '>100' and '1–5' occurrences per 1 million words, respectively (Martínez & García, 2004). Items across the HF and LF lists were matched on letter length, syllable length, and syllable structure, to their counterparts in the other frequency category. The total number of items per list containing diacritics (stress marks) was also matched. Words in the two short conditions were on average 4.7 letters and 2.0 syllables long (range: 3–6 letters; 1–2 syllables) while words in the two long conditions were on average 8.3 letters and 3.6 syllables long (range: 7–10 letters; 3–4 syllables).

Each list was printed on a white sheet of A4 paper, in a lower-case format (Calibri, 14 point) with all items in columns on two separate sheets. The participants were instructed to read aloud the words in each list as quickly and accurately as possible. Reading speed is expressed in number of seconds required to read the entire list, irrespective of reading errors, providing a pure speed measure. All Grade 3 reading accuracy measures were at ceiling in terms of accuracy (all means >95%) and did not correlate significantly with any of the cognitive variables. Indeed, given the highly transparent nature of the Spanish writing system, children's accuracy tends to approach ceiling by end of Grade 1 (Seymour, Aro, & Erskine, 2003). Furthermore, it is common for literacy acquisition studies in transparent orthographies, particularly after Grade 1, to assess reading by means of speed measures (e.g., Babayigit & Stainthorp, 2010; Lervåg et al., 2009). For this reason, the speed scores were used as the measure of reading.

Initial reading level (kindergarten). Even though the study started nine months prior to formal reading instruction, some children had been introduced, at least partially, to the alphabet, either at school or at home. Given that reading practice has been shown to influence cognitive skills (visual skill: Dehaene et al., 2010; Perfetti et al., 2013; PA: Hogan et al., 2005), it is plausible that an observed relationship between a cognitive skill and reading may be partly driven by the transformation that reading practice exerts on these cognitive skills. To guard against this possibility, early readers were excluded from the sample at the onset of the study. This procedure ensured that the cognitive skills were unmodified by reading practice at the time when they were assessed. A reading list consisting of 20 high-frequency 3- and 4-letter words was administered to the children. Only children who could not read any of these words correctly were included in the study.

Early reading level (Grade 1). A single-word reading list was administered in November of Grade 1 to measure the children's early reading level. The list comprised words of frequency >10 in 1 million, selected from a child word-frequency corpora (Martínez & García, 2004). The list included all forms of words but was composed mainly of nouns, adjectives, and adverbs. The items were ordered by increasing phono-graphic complexity, ranging from single-letter words, up to four-syllable words. Children were instructed to read the words aloud as quickly and as accurately as possible until asked to stop. Reading performance was defined as the number of correctly read items in 60 s.

Results

The descriptive statistics and reliabilities for all cognitive and literacy variables are presented in Table 1. Performance on IQ measures was within the average range. Scores on the RAN tasks, as well as those for the Grade 3 reading lists, are measures of time (in seconds) and therefore lower scores indicate better performance. This means that a positive relationship between RAN or Grade 3 reading and any other variable will be indicated by a negative correlation or path weight. Several of the measures demonstrated a slight positive skew due to the fact that a small number of children in the sample were more advanced than their peers on these tasks. The reliability for all non-standardized measures was acceptable (all rs > .70). The reliability for all measures can be observed in Table 1.

To gain an initial impression of the reading speed data a two-way repeated measures ANOVA was undertaken. The two within subject factors were word-frequency (2 levels: HF and LF) and word-length (2 levels: short and long). Unsurprisingly, there were significant main effects of word-length and word-frequency with shorter items being read significantly faster than longer items, $F(1,99) = 251.41$, $p < .001$, partial $\eta^2 = .72$, and HF words being read faster than LF words $F(1,99) = 351.66$, $p < .001$, partial $\eta^2 = .78$. More importantly, there was a significant interaction, $F(1,99) = 97.31$, $p < .001$, partial $\eta^2 = .50$, indicating that the difference between short and long words was significantly larger for LF words than for HF words.

This apparent interaction may simply be due to the fact that the slower reading times for the two LF word lists will give rise to a larger absolute difference between short- and long-LF words (compared to the difference between short- and long-HF words). Thus, the slower absolute reading times for LF words may not represent a difference in actual effect size (Faust, Balota, Spieler, & Ferraro, 1999). We therefore carried out subsequent analyses on the *proportional* changes which confirmed that the relative effect sizes between low and high frequency words were also different, hence confirming this as a genuine interaction effect. Thus, the stronger length effect for LF words suggests that HF words were predominantly read by sight, whereas LF words were decoded.

Correlation analyses

To gain a first insight into the overall relationship between visual processing skills (VPS), RAN and the reading of words with different word familiarity and length, correlation analyses were conducted. Table 2 provides results of the longitudinal correlations between all variables measured at kindergarten and all reading speed variables measured in later grades. Values above the diagonal represent estimated correlations controlling solely for chronological age, while values below the diagonal correspond to correlations controlling for both verbal IQ (Vocabulary) and non-verbal IQ (Block Design) measures, in addition to age. Given the extremely high correlations between the Grade 3 reading measures, and the large number of correlations contained in Table 2, the risk of committing a Type 1 error is inflated. To account for this, separately for correlations above and below the diagonal, the Benjamini and Hochberg (1995) adjustment was applied to control the family-wide error rate. Correlations which remained significant after this adjustment appear in Table 2 as bold values.

For many relationships the strength of the correlations weakens below the diagonal, thus confirming the need to control for IQ. Above the diagonal it can be seen that both IQ control measures were significantly correlated to other

Table 1
Means, standard deviations (*SD*) and reliability analyses for all measures.

	Mean (*SD*)	Range	Reliability
Kindergarten measures			
Non-Verbal IQ (20)	10.7 (3.61)	3–17	$\lvert r\rvert = .81(^{**})^{a}$
Verbal IQ (22)	8.6 (3.21)	1–16	$\lvert r\rvert = .82(^{**})^{a}$
Letter Knowledge (116)	26.9 (17.71)	2–102	$\alpha = .99(^{**})^{b}$
Phoneme Isolation (64)	11.3 (14.15)	2–52	$\alpha = .90(^{**})^{b}$
Phoneme Blending (10)	2.78 (2.49)	0–10	$\alpha = .87(^{**})^{b}$
RAN Pictures	58.0 (12.25)	40–87	$\lvert r\rvert = .73(^{**})^{c}$
RAN Colors	66.9 (21.82)	37–128	$\lvert r\rvert = .80(^{**})^{c}$
Visual Processing Skills (12)	7.2 (3.20)	0–12	$\alpha = .82(^{**})^{b}$
Reading speed tasks			
Grade 1 Word Reading (140)	19.63 (16.58)	0–62	$\lvert r\rvert = .88(^{**})^{c}$
Grade 3 Short High-Frequency Words	14.68 (4.39)	10–37	$\lvert r\rvert = .88(^{**})^{d}$
Grade 3 Long High-Frequency Words	22.80 (10.35)	10–68	$\lvert r\rvert = .93(^{**})^{d}$
Grade 3 Short Low-Frequency Words	26.39 (9.49)	13–60	$\lvert r\rvert = .79(^{**})^{d}$
Grade 3 Long Low-Frequency Words	42.82 (18.13)	17–129	$\lvert r\rvert = .95(^{**})^{d}$

Note. Except for the time-based tasks, the maximum score for each test is presented in parentheses following its name.

[a] Standardized test.

[b] Cronbach's Alpha.

[c] Correlations from test/re-test using the whole sample.

[d] Correlations from test/re-test using a sub-sample ($n = 68$).

[*] $p < .05$.

[**] $p < .001$.

Table 2
Correlation analyses between the control and predictor variables measured at Kindergarten, and reading measured at grades 1 and 3.

	2	3	4	5	6	7	8	9	10	11
1. K. Verbal IQ	.17	.22**	**.31****	.10	.06	.21*	–.15	–.18	–.06	–.06
2. K. Non-Verbal IQ	–	.09	.06	–**.27****	**.27****	.13	–.10	–.12	–.14	–.18
3. K. Letter Knowledge		–	**.42*****	–.17	.16	**.47*****	.06	–.04	.01	–.06
4. K. Phonological Awareness		**.38*****	–	.02	.18	**.46*****	–.08	–.07	–.06	–.11
5. K. Naming Speed (RAN)		–.19	–.01	–	–.13	–.20*	**.39*****	**.39*****	**.41*****	**.42*****
6. K. Visual Processing Skill		.14	.17	–.07	–	.22*	–.15	–.17	–.16**	–**.32****
7. G1. Word Reading		**.44*****	**.43*****	–.21*	.19	–	–**.25***	–**.28****	–**.25***	–**.36*****
8. G3. Short High-Frequency Words		.09	–.03	**.41*****	–.13	–.23*	–	**.86*****	**.77*****	**.75*****
9. G3. Long High-Frequency Words		.01	–.01	**.41*****	–.14	–**.25***	**.86*****	–	**.84*****	**.81*****
10. G3. Short Low-Frequency Words		.04	–.04	**.40*****	–.13	–**.23***	**.77*****	**.84*****	–	**.90*****
11. G3. Long Low-Frequency Words		–.04	–.09	**.40*****	–**.28****	–**.34****	**.75*****	**.82*****	**.90*****	–

Note. Above the diagonal, partial correlations with age partialed out. Below the diagonal, partial correlations with the effects of Age, Verbal and non-Verbal IQ partialed out. K = Kindergarten; G1 = Grade 1; G3 = Grade 3. Figures in bold represent correlations which remained significant after applying the Benjamini and Hochberg (1995) correction to adjust for multiple correlations.

$^{*}p < .05$.

$^{**}p < .01$.

$^{***}p < .001$.

cognitive variables. It is also notable that the IQ measures were substantially correlated with several reading variables. Below the diagonal VPS, PA and RAN showed no significant correlations between them, suggesting these three cognitive measures are largely independent of each other.

Using the below-the-diagonal correlations as a reference, this analysis revealed the different strength of the relationships between reading and the cognitive abilities of interest. Firstly, VPS showed significant correlations with Grade 3 long low-frequency words ($r = -.28$, $p < .01$), but not with long high-frequency words ($r = .14$), short low-frequency words ($r = .13$) or short high-frequency words ($r = .13$). Secondly, RAN appears to be the most consistent and powerful longitudinal correlate of Grade 3 reading speed ($r_{SHF} = .41$, $r_{LHF} = .41$, $r_{SLF} = .40$, $r_{LLF} = .40$, all $ps < .001$). Finally, we note that, while being highly significantly correlated to Grade 1 reading ($r = .43$, $p < .001$), PA was not significantly correlated with any Grade 3 reading speed measures ($r_{SHF} = .03$, $r_{LHF} = .01$, $r_{SLF} = .04$, $r_{LLF} = .09$, all $ps > .37$). This latter result agrees with similar studies carried out in shallow orthographies. From this initial analysis, VPS and RAN appear to be longitudinal predictors of reading in Spanish over and above the contribution made by age and IQ.

Longitudinal path analyses

To assess the contribution of kindergarten VPS, RAN and PA as predictors of individual reading fluency of different types of words in Grade 3, we conducted a series of path analyses in Mplus (Version 6.1; Muthén & Muthén, 2010). To account for the potential statistical biases resulting from the non-normality of some distributions, we used maximum-likelihood method with robust standard errors (Asparouhov & Muthén, 2005) along with the Yuan-Bentler scaled χ^2 difference test (Yuan & Bentler, 2000). Before conducting the analyses, the four reading scores were standardized. Separately for each reading condition, we first estimated a saturated model with all possible correlations between the predictor variables (VPS, RAN and PA) and the control variables (age, LK, verbal IQ and non-verbal IQ) along with all possible paths from these variables to both Grade 1 and Grade 3 reading. All relationships involving the three predictor variables were retained, while non-significant correlations and paths involving the control variables were dropped iteratively. Changes in model fit were examined until a simplified model was obtained in which all remaining paths and covariances were statistically significant, or involved the three predictor variables.

For clarity, Fig. 1 shows just the relationships between VPS, RAN and PA and the four reading measures, taken from these simplified models. All models provide a good fit to the data. For all four types of words RAN proved to be a significant predictor of variation in reading skill. Additionally, VPS explained significant additional variance on long, low frequency word reading. Unsurprisingly, given that pre-reading PA has been shown not to explain variation in reading in shallow orthographies beyond Grade 1, PA did not explain variation in any of the four Grade 3 reading conditions.

It is apparent from Fig. 1 that the predictive power of VPS is much stronger for long, low-frequency words compared to other types of words. It also appears as though the path weights for RAN are all very similar, suggesting that the predictive power of RAN is equal for each type of word. To formally test these observations we created an additional path model in which all four word types were included in the one model as separate endogenous variables with separate paths from all predictors and Grade 1 reading to each one. After first fitting the saturated model, non-significant paths were removed as described above. The resulting simplified model fit the data well, $\chi^2(10, N = 100) = 6.03$, $p = .81$, TLI = 1.03, SRMR = .036, RMSEA = .000 (90% CI = .000–.068). We then constrained the four path weights originating from RAN to be the same. The Yuan-Bentler scaled χ^2 difference test was not significant ($\Delta\chi^2[3] = 0.14$, $p > .05$), confirming that RAN's predictive power did not differ with word type. In contrast, when we constrained the four path weights originating from VPS to be the same, the Yuan-Bentler scaled χ^2 difference test was significant ($\Delta\chi^2[3] = 20.89$, $p < .001$). Subsequent testing confirmed that the path weight from VPS to long low-frequency words was significantly stronger compared to all other types of words.

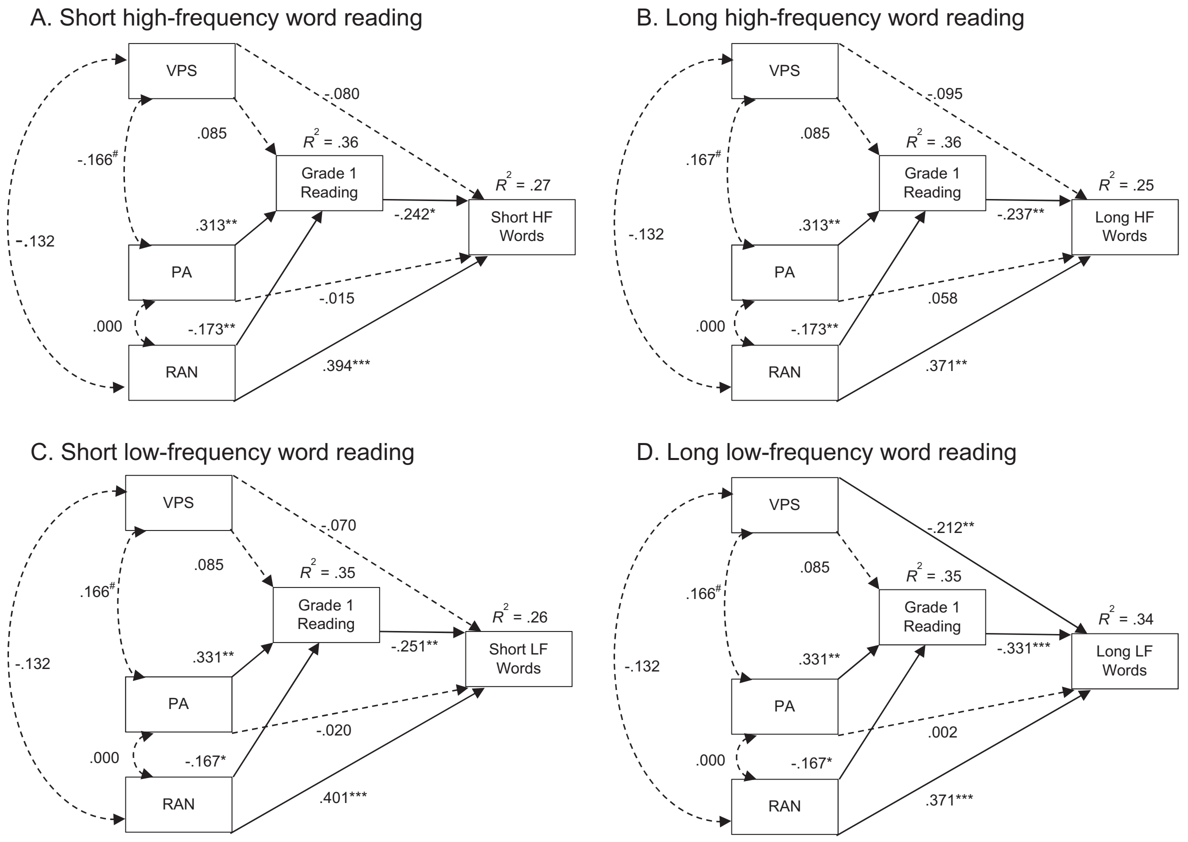

Fig. 1. Four path analysis models predicting (A) short high frequency reading ability, (B) long high frequency reading ability, (C) short low frequency reading ability, and (D) long low frequency reading ability, from cognitive variables. *Note.* Fit indices are: (A) $\chi^2(4, N = 100) = 2.88$, $p = .48$, TLI = 1.06, SRMR = .016, RMSEA = .000 (90% CI = .000–.130); (B) $\chi^2(4, N = 100) = 3.26$, $p = .51$, TLI = 1.04, SRMR = .017, RMSEA = .026 (90% CI = .000–.138); (C) $\chi^2(6, N = 100) = 4.61$, $p = .60$, TLI = 1.05, SRMR = .026, RMSEA = .034 (90% CI = .000–.112); (D) $\chi^2(6, N = 100) = 3.28$, $p = .77$, TLI = 1.08, SRMR = .022, RMSEA = .000 (90% CI = .000–.088). Standardized path weights are shown. Solid arrows represent statistically significant relationships. Dashed paths represent non-significant relationships. $^{\#}p < .1$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. Non-significant relationships involving control variables were dropped from the simplified models. For clarity, the control variables age, verbal IQ and non-verbal IQ are not shown in the figures. RAN = rapid automatized naming; VPS = visual processing skills; PA = phonological awareness; TLI = Tucker Lewis index; SRMR = standardized root mean square residual; RMSEA = root mean square error of approximation.

When using a dependent variable which combined the reading speed and accuracy measures, the main pattern of results remain unchanged and the magnitude of the co-efficients remains very similar in all cases.

Discussion

The present study explored the influence that visual processing skill (VPS), as measured through multi-element processing (MEP), has on reading performance as a function of word -familiarity and -length, with familiarity regulated by means of word-frequency. The aim was to examine whether MEP is predominantly related to sight-word reading of familiar words or to decoding of unfamiliar words. Visual skill was assessed before the onset of reading instruction by measuring the children's ability to visually process multiple elements within a string of non-verbal symbols. When measuring reading in Grade 3, there was reliable evidence of a stronger length effect for low-frequency words than for high-frequency words. This result indicates that low-frequency words were unfamiliar to the children and were therefore decoded, whereas high-frequency words were recognized as familiar and read by sight.

Longitudinal path analyses revealed that pre-reading MEP significantly predicted word reading speed in Grade 3, beyond the contributions made by RAN, PA, LK, IQ and Grade 1 reading performance, provided the words were both unfamiliar and long. This result indicates that future sublexical decoding, but not by sight-word reading, is related on pre-reading MEP. Furthermore, the contribution by visual multi-element processing to long-, but not short-, word reading suggests that decoding speed is somewhat dependent on the ability to accurately process wide multi-element arrays. Finally, RAN emerged as a robust longitudinal predictor of the reading speed of all Grade 3 word types, while PA did not contribute to reading beyond Grade 1.

Multi-element processing predicts decoding, not sight-word reading

Noting that the present study measured visual processing skill before the onset of formal literacy instruction and at a time when none of the children in the sample could read, the current results indicate that individual differences in pre-reading visual processing significantly predict future reading acquisition. Furthermore, pre-reading visual skill made a significant contribution to Grade 3 reading after controlling for Grade 1 reading performance, indicating that the contribution is direct. This result is in line with the previous finding of Franceschini et al. (2012) in Italian. Moreover, the visual multi-element processing task used in the present study was comprised of non-verbal stimuli (as the symbols used were unknown to the children) and the required responses were non-verbal. Thus, these results could not have been driven by individual differences in phonological skill or letter knowledge. Therefore, the present study extends previous findings of a significant link between multi-element visual processing of symbol strings and reading skill (Bosse & Valdois, 2009; Hawelka & Wimmer, 2005; Jones et al., 2008; Pammer et al., 2004) by providing evidence for the first time that *pre-reading* performance on symbol-position encoding, a pure visual processing task, is significantly related to future reading (i.e., specifically, decoding of long unfamiliar words).

The difference between short and long words was significantly larger for LF- than for HF- words. This word-length by word-frequency interaction on reading latencies is important because it is a clear indication of two distinct reading processes: lexical/sight-word reading for high frequency words and serial decoding for low-frequency words (Weekes, 1997; Ziegler et al., 2001). Furthermore, the influence of visual skill on word reading was moderated by word-length and word-familiarity. The finding where visual skill, as measured through MEP, predicted long low-frequency word reading, but not high-frequency word reading, indicates that pre-reading MEP is not a significant predictor of future sight-word reading of familiar words.

The current results are in line with studies which found a link between visual ability, measured through visual spatial attention skill tasks, and the accuracy with which readers process unfamiliar letters-strings (Auclair & Siéroff, 2002; Collis et al., 2013; Facoetti et al., 2006; Jones et al., 2008; Kinsey, Rose, Hansen, Richardson, & Stein, 2004). After finding that performance on a movement-perception task was related to non-word reading ability, but not to exception word reading ability (sight-word reading), Cestnick and Coltheart (1999) concluded that unfamiliar-word reading requires a serial left-to-right allocation of covert attention across the letter string. Likewise, the CDP+ model (Perry et al., 2007) predicts that spatial attention skills should primarily affect the decoding strategy, while Ziegler et al.'s (2014) extension of this model can simulate how visual deficits (letter-position encoding errors) affect unfamiliar-word reading. Interestingly, according to this model this visual deficit also affects the sort of orthographic learning which would be necessary for future sight-word reading. Valdois et al. (2006) found that reading of long unfamiliar words specifically engages a network of brain regions involved in visual attention processing. The combination of these previously reported results along with the present finding suggests that visual processing skill plays a part in analytical decoding of novel words. According to Jones et al. (2008), the effectiveness in guiding attention serially over the letter string might be particularly pertinent for decoding of unfamiliar words.

Furthermore, the current study found that MEP was a significant predictor only when reading long unfamiliar words, but not short unfamiliar words. However, the relationship was between MEP and reading *speed*, rather than *accuracy*. The idea that MEP might play a role in how rapidly long (but not short) words are decoded, rather than how accurately they are decoded, can be best understood under the assumption that the maximum number of letters in a multi-element array which can be accurately processed by an individual influences their reading speed (Häikiö et al., 2009; Kwon et al., 2007; Lobier et al., 2013; Rayner et al., 2010). This is consistent with the findings of Bosse et al. (2007) who found that visual attention span deficits made significant contributions to reading speed. Furthermore, Hawelka and Wimmer (2005) reported that readers with dyslexia exhibited a digit-position encoding impairment for four- and six-digit strings but not for two-digit strings, which they described as a visual multi-element processing deficit. Being able to unitize large letter-clusters as individual units, which increases reading speed (Ehri, 2005; LaBerge & Samuels, 1974), might be dependent on an ability to accurately process multi-element arrays.

Plausible explanations for contradicting results

The present study found a significant independent contribution by pre-reading multi-element processing to future unfamiliar-word reading, but not familiar-word reading. In contrast, other studies conducted in both transparent and opaque orthographies have found MEP to significantly contribute to both familiar and unfamiliar word reading (French: Bosse et al., 2007; English: Bosse & Valdois, 2009; Spanish: Lallier et al., 2014; Dutch: van den Boer et al., 2013). A common feature of all of these studies is that they all used visual tasks in which the items were composed of letters. However, the current study's use of non-verbal stimuli in the visual task sets it apart. Despite the fact that some of these studies controlled for 'letter identification' skill it is still plausible that the correlation between letter knowledge and reading (Bowey, 2005) inflated the correlation between familiar word reading and visual skill. More importantly, these studies comprised samples of children with at least one year's reading experience. Therefore, it cannot be ruled out that reading practice might have already improved visual ability (Dehaene et al., 2010; Perfetti et al., 2013), thus increasing the strength of the correlation between the multi-element processing and sight-word reading. This possibility could lead to an erroneous interpretation of the direction of causality between familiar word reading and visual skills.

Considering the present results, it is not immediately obvious why multi-element processing would be important for serially decoding sublexical segments, but not for recognizing whole-word forms. According to the MTM model (Ans et al., 1998) the visual attentional window delineates the amount of orthographic information which attention can be simultaneously focused on during word reading (Lallier & Valdois, 2012). In this model's global reading procedure (similar to the concept of sight-word reading) the window opens over the whole letter string, whereas in analytic mode (i.e., decoding) it narrows to focus attention on each orthographic sub-unit of the input word. Therefore, a reduced ability to process multi-element arrays should be particularly detrimental with regards to familiar-word reading which, just like MEP tasks, requires strings of letters to be correctly recognized. However, in contrast to the aforementioned studies, the results of this study indicate that a reduced MEP ability affects decoding more than sight-word reading.

The fact that MEP was measured by means of a symbol-position encoding task might explain why MEP would be more relevant for serial decoding than for parallel sight-word reading. An important aspect of the dual-route orthographic processing approach (Grainger & Ziegler, 2011; Grainger et al., 2016) is the notion that sight-word reading relies on flexible, relatively imprecise orthographic representations, which allow for faster whole-word identification via salient orthographic features. In line with this perspective, Reynolds and Besner (2006) found that activation of the orthographic lexicon when reading aloud did not require attentional resources. In contrast, the use of more precise position-encoded letter identities during decoding appears to be more demanding on attentional resources, enabling an accurate representation of within-word letter order (Grainger & Ziegler, 2011). This perspective is consistent with studies which found a specific link between visual spatial attention and unfamiliar-word reading (Auclair & Siéroff, 2002; Cestnick & Coltheart, 1999; Facoetti et al., 2006, 2010; Kinsey et al., 2004), and may explain why our symbol-position encoding measure is more related to decoding than to sight-word reading.

An alternative explanation for this difference in results is that in the MEP tasks used in previous studies (e.g., Bosse & Valdois, 2009; Jones et al., 2008; Pammer et al., 2004) the participants were exposed to the target for between 100 and 200 ms, whereas in the MEP task of the current study the exposure time was much longer. Even though it varies as a function of the specific situation, the time needed to encode the location of a target in the visual field and initiate an eye movement is on average 175–200 ms for adults (Rayner, 2009) and 200–300 ms for children (Häikiö et al., 2009). Longer exposure should allow the participant to exercise serial orienting of attention across the multi-element array. The implication may be that sight-word reading speed might rely on the amount of visual elements which can be simultaneously processed at glance, while decoding speed, as well as this study's MEP task, might be more reliant on a comparatively time-consuming serial orienting of attention. Therefore it is conceivable that the visual skill which sight-word reading is dependent on is best measured by a MEP task other than the one used in this study.

Accordingly, future research should also study whether different types of visual skills (e.g., visual searching ability, visual attention span, symbol-position encoding skill, visuo-spatial ability, etc.) are differently involved in reading. On the one hand, it is conceivable that many of these tasks tap on the same core visual skill (e.g., visual attention). For instance, Jones et al. (2008) found a positive correlation between visual-search and MEP scores, which they interpreted as an indication that both skills share a common mechanism which is applied when rapidly guiding serial attention across the word. On the other hand, different visual tasks may very well measure different visual skills (Rayner, 2009 for a review) and not all types of visual skills are necessarily relevant to reading. Furthermore, visual skills which are related to reading might be involved in different aspects of reading (e.g., speed vs. accuracy). Precisely in what manner MEP is related to decoding speed (e.g., visual attention span vs. visual-attentional orienting speed) deserves further attention. Thus, future studies should compare the contributions made by different types of visual skills to reading in order to assess whether they share the same underlying processes.

Also, despite the claim that whole word reading requires a larger visual attention span than does decoding (e.g., Ans et al., 1998; van den Boer et al., 2013), there is relatively little research which has actually looked at this specific issue. It would be advantageous if future MEP studies used experimental means which explore how visual attention is distributed over a string. For example, a number of studies have utilized the moving window paradigm, in which the size and the symmetry of the visual window are varied, in order to investigate the perceptual span in reading (Rayner, 2014 for a review). Through this means, evidence has been presented which indicates that the visual span of younger or less proficient readers is smaller than that of older (Häikiö et al., 2009; Rayner, 1986) or more proficient readers (Rayner et al., 2010), respectively. Likewise, assessing whether MEP ability can predict performance on the moving window paradigm would be a useful manner to explore the MEP-reading relationship.

Moreover, it must be noted that this study relied on individual-word reading measures. It is plausible that during text reading, which relies more heavily on parafoveal preview (see Schotter, Angele, & Rayner, 2012 for a review), sight-word reading might be significantly dependent on MEP ability. This is the type of assumption which could be tested by means of the moving window paradigm. Finally, higher proficiency readers appear to make more efficient use of information extracted from the words within their perceptual span than do less proficient readers (Veldre & Andrews, 2015a, 2015b), which raises the possibility that MEP ability might be determined not only by the size of the visual span, but also by the accuracy with which symbol strings are processed within that span.

The influence of naming speed and phonemic awareness on reading

Although RAN emerged as the only predictor of familiar word reading, its contribution to HF words was no stronger than to LF words. This replicates the findings of other studies which also found similar contributions made by RAN to word reading, irrespective to word familiarity (Moll et al., 2009; Poulsen & Elbro, 2013; van den Boer et al., 2013). The effect of RAN was also not moderated by word length. Taken together, the results of the familiarity and length manipulations suggest that RAN taps onto a cognitive skill which is common to decoding of unfamiliar words and sight-word reading of familiar words.

Finally, we note that, despite PA's strong contribution to Grade 1 reading ($r = .46$), pre-reading PA did not make a significant contribution to Grade 3 reading, irrespective of word familiarity or length manipulations. While PA's short-lived relationship with reading may seem surprising to anybody only familiar to reading development in English, this result is in agreement with similar studies carried out in regular orthographies. Previous findings firmly support the notion that in transparent orthographies early levels of PA become irrelevant to reading in later years (Norwegian: Lervåg et al., 2009; Dutch: De Jong & van der Leij, 1999; German: Landerl & Wimmer, 2000, 2008; Spanish: Defior, 2008).

Conclusions

The main purpose of the present study was to assess whether pre-reading visual processing skills, measured through multi-element processing of non-verbal symbols, significantly contributes to word decoding or sight-word reading. For the first time, our results demonstrate the pre-reading MEP, a pure visual ability task, makes a significant, independent and direct contribution to future reading – specifically, the reading speed of long low frequency words. This finding suggests that, at least in a transparent orthography as Spanish, a child's pre-reading multi-element processing skill is predictive of future word decoding. Furthermore, the fact that multi-element processing made a significant contribution to long, but not short, unfamiliar-word reading suggests that the number of visual elements which can be processed in a multi-element array may determine decoding speed. Finally, the longitudinal nature of the study and the fact that these cognitive measures were assessed prior to the onset of reading skill acquisition clearly identifies the direction of the relationship. Thus, our findings advocate further investigation regarding the role visual processing skill plays in reading.

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Appendix A. Word familiarity lists

Short Words		Long Words	
HF	LF	HF	LF
Sol	Fax	Círculo	Fósforo
Ojo	Eje	Montaña	Consumo
Luz	Bol	Domingo	Rotonda
Año	Osa	Ventana	Zancada
Suma	Fuga	Palabra	Mudanza
Boca	Reto	Momento	Culebra
Isla	Orca	Todavía	Trópico
Mamá	Paté	Príncipe	Tránsito
Vida	Rizo	Muchacho	Cartucho
Diez	Leal	Problema	Frontera
Algo	Olmo	Bastante	Tornillo
Color	Letal	Castillo	Vibrante
Mundo	Himno	Personas	Maniobra
Fácil	Fósil	Caliente	Temporal
Coche	Rifle	Resultado	Caníbales
Nadie	Goteo	Comunidad	Totalidad
Jardín	Fértil	Caramelos	Incorrecta
Medio	Mafia	Personaje	Camuflaje
Reina	Ruina	Alimentos	Elemental
Tiempo	Pócima	Chocolate	Manifiesto
Música	Huelga	Enseguida	Cerrajero
Pueblo	Golosa	Importante	Maleficios
Dinero	Agenda	Movimiento	Granizado
Enorme	Masaje	Televisión	Ingeniero
Comida	Buitre	Cumpleaños	Malcriados

References

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

Asparouhov, T., & Muthén, B. (2005). Multivariate statistical modeling with survey data. *Paper presented at the proceedings of the federal committee on statistical methodology (FCSM) research conference.* Retrieved from <http://www.fcsm.gov/05papers/Asparouhov_Muthen_IIA.pdf>.

Auclair, L., & Siéroff, E. (2002). Attentional cueing effect in the identification of words and pseudowords of different length. *The Quarterly Journal of Experimental Psychology Section A, 55*(2), 445–463. http://dx.doi.org/10.1080/02724980143000415.

Babayigit, S., & Stainthorp, R. (2010). Component processes of early reading, spelling, and narrative writing skills in Turkish: A longitudinal study. *Reading and Writing, 23*(5), 539–568. http://dx.doi.org/10.1007/s11145-009-9173-y.

Backman, J., Bruck, M., Hebert, M., & Seidenberg, M. S. (1984). Acquisition and use of spelling-sound correspondences in reading. *Journal of Experimental Child Psychology, 38*(1), 114–133. http://dx.doi.org/10.1016/0022-0965(84)90022-5.

Barca, L., Burani, C., & Arduino, L. S. (2002). Word naming times and psycholinguistic norms for Italian nouns. *Behavior Research Methods, Instruments, and Computers, 34*(3), 424–433.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological), 57*(1), 289–300.

Bentin, S., & Leshem, H. (1993). On the interaction between phonological awareness and reading acquisition: It's a two-way Street. *Annals of Dyslexia, 43*(1), 125–148. http://dx.doi.org/10.1007/BF02928178.

Bonin, P., Barry, C., Méot, A., & Chalard, M. (2004). The influence of age of acquisition in word reading and other tasks: A never ending story? *Journal of Memory and Language, 50*(4), 456–476. http://dx.doi.org/10.1016/j.jml.2004.02.001.

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

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. http://dx.doi.org/10.1111/j.1467-9817.2008.01387.x.

Bowey, J. A. (2005). Predicting individual differences in learning to read. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 155–172). Malden: Blackwell Publishing.

Cairns, N. U., & Steward, M. S. (1970). Young children's orientation of letters as a function of axis of symmetry and stimulus alignment. *Child Development, 41*(4), 993–1002.

Cestnick, L., & Coltheart, M. (1999). The relationship between language-processing and visual-processing deficits in developmental dyslexia. *Cognition, 71*(3), 231–255.

Collis, N. L., Kohnen, S., & Kinoshita, S. (2013). The role of visual spatial attention in adult developmental dyslexia. *The Quarterly Journal of Experimental Psychology, 66*(2), 245–260. http://dx.doi.org/10.1080/17470218.2012.705305.

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.

Cuetos, F., & Barbón, A. (2006). Word naming in Spanish. *European Journal of Cognitive Psychology, 18*(3), 415–436. http://dx.doi.org/10.1080/13594320500165896.

De Jong, P. F., & van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a Dutch latent variable longitudinal study. *Journal of Educational Psychology, 91*(3), 450–476. http://dx.doi.org/10.1037/0022-0663.91.3.450.

Defior, S. (2008). How to facilitate initial literacy acquisition: The role of phonological skills. *Infancia y Aprendizaje, 31*(3), 333–345. http://dx.doi.org/10.1174/021037008785702983.

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes Filho, G., Jobert, A., ... Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *Science, 330*(6009), 1359–1364. http://dx.doi.org/10.1126/science.1194140.

Denckla, M. B., & Rudel, R. (1974). Rapid automatized naming of pictured objects, colors, letters and numbers by normal children. *Cortex, 10*(2), 186–202. http://dx.doi.org/10.1016/S0010-9452(74)80009-2.

Ehri, L. C. (2005). Development of sight word reading: Phases and findings. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 135–154). Malden: Blackwell Publishing.

Facoetti, A., Ruffino, M., Peru, A., Paganoni, P., & Chelazzi, L. (2008). Sluggish engagement and disengagement of non-spatial attention in dyslexic children. *Cortex, 44*(9), 1221–1233. http://dx.doi.org/10.1016/j.cortex.2007.10.007.

Facoetti, A., Trussardi, A. N., Ruffino, M., Lorusso, M. L., Cattaneo, C., Galli, R., ... Zorzi, M. (2010). Multisensory spatial attention deficits are predictive of phonological decoding skills in developmental dyslexia. *Journal of Cognitive Neuroscience, 22*(5), 1011–1025. http://dx.doi.org/10.1162/jocn.2009.21232.

Facoetti, A., Zorzi, M., Cestnick, L., Lorusso, M. L., Molteni, M., Paganoni, P., ... Mascetti, G. G. (2006). The relationship between visuo-spatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology, 23*(6), 841–855. http://dx.doi.org/10.1080/02643290500483090.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125*(6), 777–799. http://dx.doi.org/10.1037/0033-2909.125.6.777.

Forster, K. I., & Chambers, S. M. (1973). Lexical access and naming time. *Journal of Verbal Learning and Verbal Behavior, 12*(6), 627–635. http://dx.doi.org/10.1016/S0022-5371(73)80042-8.

Franceschini, S., Gori, S., Ruffino, M., Pedrolli, K., & Facoetti, A. (2012). A causal link between visual spatial attention and reading acquisition. *Current Biology, 22*(9), 814–819. http://dx.doi.org/10.1016/j.cub.2012.03.013.

Gori, S., & Facoetti, A. (2015). How the visual aspects can be crucial in reading acquisition: The intriguing case of crowding and developmental dyslexia. *Journal of Vision, 15*(1), 1–20. http://dx.doi.org/10.1167/15.1.8.

Goswami, U. (2015a). Sensory theories of developmental dyslexia: Three challenges for research. *Nature Reviews Neuroscience, 16*(1), 43–54. http://dx.doi.org/10.1038/nrn3836.

Goswami, U. (2015b). Visual attention span deficits and assessing causality in developmental dyslexia. *Nature Reviews Neuroscience, 16*(4), 225–226. http://dx.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. http://dx.doi.org/10.1016/j.tics.2015.12.008.

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology, 2*(APR). http://dx.doi.org/10.3389/fpsyg.2011.00054.

Häikiö, T., Bertram, R., Hyönä, J., & Niemi, P. (2009). Development of the letter identity span in reading: Evidence from the eye movement moving window paradigm. *Journal of Experimental Child Psychology, 102*(2), 167–181. http://dx.doi.org/10.1016/j.jecp.2008.04.002.

Hawelka, S., & Wimmer, H. (2005). Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading. *Vision Research, 45*(7), 855–863. http://dx.doi.org/10.1016/j.visres.2004.10.007.

Hawelka, S., & Wimmer, H. (2008). Visual target detection is not impaired in dyslexic readers. *Vision Research, 48*(6), 850–852. http://dx.doi.org/10.1016/j.visres.2007.11.003.

Hogan, T. P., Catts, H. W., & Little, T. D. (2005). The relationship between phonological awareness and reading: Implications for the assessment of phonological awareness. *Language, Speech, and Hearing Services in Schools, 36*(4), 285–293.

Jones, M. W., Branigan, H. P., & Kelly, M. L. (2008). Visual deficits in developmental dyslexia: Relationships between non-linguistic visual tasks and their contribution to components of reading. *Dyslexia, 14*(2), 95–115. http://dx.doi.org/10.1002/dys.345.

Kinsey, K., Rose, M., Hansen, P., Richardson, A., & Stein, J. (2004). Magnocellular mediated visual-spatial attention and reading ability. *NeuroReport, 15*(14), 2215–2218. http://dx.doi.org/10.1097/00001756-200410050-00014.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*(3), 453–464.

Kirby, J. R., Roth, L., Desrochers, A., & Lai, S. S. V. (2008). Longitudinal predictors of word reading development. *Canadian Psychology, 49*(2), 103–110. http://dx.doi.org/10.1037/0708-5591.49.2.103.

Kuperman, V., Van Dyke, J. A., & Henry, R. (2016). Eye-movement control in RAN and reading. *Scientific Studies of Reading, 20*, 173–188.

Kwon, M., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual span for reading. *Vision Research, 47*(22), 2889–2900. http://dx.doi.org/10.1016/j.visres.2007.08.002.

LaBerge, D., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*(2), 293–323. http://dx.doi.org/10.1016/0010-0285(74)90015-2.

Lallier, M., & Valdois, S. (2012). Sequential versus simultaneous processing deficits in developmental dyslexia. In T. Wydell & L. Fern-Pollack (Eds.), *Dyslexia: A comprehensive and international approach* (pp. 73–108). In Tech Online Publishers.

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. http://dx.doi.org/10.1016/j.ridd.2014.01.021.

Landerl, K., & Wimmer, H. (2000). Deficits in phoneme segmentation are not the core problem of dyslexia: Evidence from German and English children. *Applied Psycholinguistics, 21*(2), 243–262.

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*(1), 150–161. http://dx.doi.org/10.1037/0022-0663.100.1.150.

Leppänen, U., Niemi, P., Aunola, K., & Nurmi, J.-E. (2006). Development of reading and spelling Finnish from preschool to grade 1 and grade 2. *Scientific Studies of Reading, 10*(1), 3–30. http://dx.doi.org/10.1207/s1532799xssr1001_2.

Lervåg, A., Bråten, I., & Hulme, C. (2009). The cognitive and linguistic foundations of early reading development: A Norwegian latent variable longitudinal study. *Developmental Psychology, 45*(3), 764–781. http://dx.doi.org/10.1037/a0014132.

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

Lobier, M., & Valdois, S. (2015). Visual attention deficits in developmental dyslexia cannot be ascribed solely to poor reading experience. *Nature Reviews. Neuroscience, 16*(4), 225. http://dx.doi.org/10.1038/nrn3836-c1.

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

Lovegrove, W., Martin, F., & Slaghuis, W. (1986). A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology, 3*(2), 225–267. http://dx.doi.org/10.1080/02643298608252677.

Marinus, E., & de Jong, P. F. (2010). Variability in the word-reading performance of dyslexic readers: Effects of letter length, phoneme length and digraph presence. *Cortex, 46*(10), 1259–1271. http://dx.doi.org/10.1016/j.cortex.2010.06.005.

Martínez, J. A., & García, E. (2004). *Diccionario: Frecuencias del castellano escrito en niños de 6 a 12 años*. Universidad Pontificia de Salamanca.

Mason, M., & Katz, L. (1976). Visual processing of nonlinguistic strings: Redundancy effects and reading ability. *Journal of Experimental Psychology: General, 105*(4), 338–348. http://dx.doi.org/10.1037/0096-3445.105.4.338.

McBride-Chang, C., Zhou, Y., Cho, J.-R., Aram, D., Levin, I., & Tolchinsky, L. (2011). Visual spatial skill: A consequence of learning to read? *Journal of Experimental Child Psychology, 109*(2), 256–262. http://dx.doi.org/10.1016/j.jecp.2010.12.003.

Moll, K., Fussenegger, B., Willburger, E., & Landerl, K. (2009). RAN is not a measure of orthographic processing. Evidence from the asymmetric German orthography. *Scientific Studies of Reading, 13*(1), 1–25. http://dx.doi.org/10.1080/10888430802631684.

Muthén, L. K., & Muthén, B. O. (2010). *Mplus user's guide* (6th ed.). Los Angeles, CA: Author.

Öney, B., & Durgunoğlu, A. Y. (1997). Beginning to read in Turkish: A phonologically transparent orthography. *Applied Psycholinguistics, 18*(01), 1–15. http://dx.doi.org/10.1017/S014271640000984X.

Pammer, K., Lavis, R., Hansen, P., & Cornelissen, P. L. (2004). Symbol-string sensitivity and children's reading. *Brain and Language, 89*(3), 601–610. http://dx.doi.org/10.1016/j.bandl.2004.01.009.

Perfetti, C., Cao, F., & Booth, J. (2013). Specialization and universals in the development of reading skill: How Chinese research informs a universal science of reading. *Scientific Studies of Reading, 17*(1), 5–21. http://dx.doi.org/10.1080/10888438.2012.689786.

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*(2), 273–315. http://dx.doi.org/10.1037/0033-295X.114.2.273.

Plaza, M., & Cohen, H. (2007). The contribution of phonological awareness and visual attention in early reading and spelling. *Dyslexia, 13*(1), 67–76. http://dx.doi.org/10.1002/dys.330.

Poulsen, M., & Elbro, C. (2013). What's in a name depends on the type of name: The relationships between semantic and phonological access, reading fluency, and reading comprehension. *Scientific Studies of Reading, 17*(4), 303–314. http://dx.doi.org/10.1080/10888438.2012.692743.

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology, 41*(2), 211–236. http://dx.doi.org/10.1016/0022-0965(86)90037-8.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62*(8), 1457–1506. http://dx.doi.org/10.1080/17470210902816461.

Rayner, K. (2014). The gaze-contingent moving window in reading: Development and review. *Visual Cognition, 22*(3), 242–258. http://dx.doi.org/10.1080/13506285.2013.879084.

Rayner, K., Slattery, T. J., & Bélanger, N. N. (2010). Eye movements, the perceptual span, and reading speed. *Psychonomic Bulletin & Review, 17*(6), 834–839. http://dx.doi.org/10.3758/PBR.17.6.834.

Reynolds, M., & Besner, D. (2006). Reading aloud is not automatic: Processing capacity is required to generate a phonological code from print. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1303–1323. http://dx.doi.org/10.1037/0096-1523.32.6.1303.

Rodríguez, C., van den Boer, M., Jiménez, J. E., & de Jong, P. F. (2015). Developmental changes in the relations between RAN, phonological awareness, and reading in Spanish children. *Scientific Studies of Reading, 19*(4), 273–288. http://dx.doi.org/10.1080/10888438.2015.1025271.

Schotter, E. R., Angele, B., & Rayner, K. (2012). Parafoveal processing in reading. *Attention, Perception, and Psychophysics, 74*(1), 5–35. http://dx.doi.org/10.3758/s13414-011-0219-2.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology (London, England: 1953), 94*(Pt 2), 143–174. http://dx.doi.org/10.1348/000712603321661859.

Shapiro, L. R., Carroll, J. M., & Solity, J. E. (2013). Separating the influences of prereading skills on early word and nonword reading. *Journal of Experimental Child Psychology, 116*(2), 278–295. http://dx.doi.org/10.1016/j.jecp.2013.05.011.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition, 55*(2), 151–218.

Share, D. L. (2008). On the Anglocentricities of current reading research and practice: The perils of overreliance on an «outlier» orthography. *Psychological Bulletin, 134*(4), 584–615. http://dx.doi.org/10.1037/0033-2909.134.4.584.

Spinelli, D., De Luca, M., Judica, A., & Zoccolotti, P. (2002). Crowding effects on word identification in developmental dyslexia. *Cortex, 38*(2), 179–200.

Suárez-Coalla, P., García-De-Castro, M., & Cuetos, F. (2013). Predictors of reading and writing in Spanish. *Infancia y Aprendizaje, 36*(1), 77–89. http://dx.doi.org/10.1174/021037013804826537.

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. http://dx.doi.org/10.1002/dys.284.

Valdois, S., Carbonnel, S., Juphard, A., Baciu, M., Ans, B., Peyrin, C., & Segebarth, C. (2006). Polysyllabic pseudo-word processing in reading and lexical decision: Converging evidence from behavioral data, connectionist simulations and functional MRI. *Brain Research, 1085*(1), 149–162. http://dx.doi.org/10.1016/j.brainres.2006.02.049.

van den Boer, M., & de Jong, P. F. (2015). Parallel and serial reading processes in children's word and nonword reading. *Journal of Educational Psychology, 107*(1), 141–151. http://dx.doi.org/10.1037/a0037101.

van den Boer, M., de Jong, P. F., & Haentjens-van Meeteren, M. M. (2013). Modeling the length effect: Specifying the relation with visual and phonological correlates of reading. *Scientific Studies of Reading, 17*(4), 243–256. http://dx.doi.org/10.1080/10888438.2012.683222.

van den Bos, K. P., Zijlstra, B. J. H., & Lutje Spelberg, H. C. (2002). Life-span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word-reading speed. *Scientific Studies of Reading, 6*(1), 25–49. http://dx.doi.org/10.1207/S1532799XSSR0601_02.

Veldre, A., & Andrews, S. (2015a). Parafoveal lexical activation depends on skilled reading proficiency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(2), 586–595. http://dx.doi.org/10.1037/xlm0000039.

Veldre, A., & Andrews, S. (2015b). Parafoveal preview benefit is modulated by the precision of skilled readers' lexical representations. *Journal of Experimental Psychology: Human Perception and Performance, 41*(1), 219–232. http://dx.doi.org/10.1037/xhp0000017.

Vellutino, F. R., Scanlon, D. M., Small, S. G., & Tanzman, M. S. (1991). The linguistic bases of reading ability: Converting written to oral language. *Text, 11*(1), 97–166. http://dx.doi.org/10.1515/text.1.1991.11.1.97.

Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Sciences, 14*(2), 57–63. http://dx.doi.org/10.1016/j.tics.2009.12.003.

Wechsler, D. (2001). *WPPSI-III: Escala de inteligencia de Wechsler para preescolar y primaria*. Madrid: Tea.

Weekes, B. S. (1997). Differential effects of number of letters on word and nonword naming latency. *The Quarterly Journal of Experimental Psychology Section A, 50*(2), 439–456. http://dx.doi.org/10.1080/713755710.

Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., ... Green, G. G. R. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. *Current Biology, 8*(14), 791–797.

Yamazaki, M., Ellis, A. W., Morrison, C. M., & Ralph, M. A. L. (1997). Two age of acquisition effects in the reading of Japanese Kanji. *British Journal of Psychology, 88*(3), 407–421. http://dx.doi.org/10.1111/j.2044-8295.1997.tb02648.x.

Yuan, K.-H., & Bentler, P. M. (2000). Three likelihood-based methods for mean and covariance structure analysis with nonnormal missing data. In M. E. Sobel & M. P. Becker (Eds.), *Sociological methodology 2000* (pp. 165–200). Washington, DC: ASA.

Ziegler, J. C., Pech-Georgel, C., Dufau, S., & Grainger, J. (2010). Rapid processing of letters, digits and symbols: What purely visual-attentional deficit in developmental dyslexia? *Developmental*

Science, 13(4), F8–F14. http://dx.doi.org/10.1111/j.1467-7687.2010.00983.x.

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. http://dx.doi.org/10.1111/1467-9280.00370.

Ziegler, J. C., Perry, C., & Zorzi, M. (2014). Modelling reading development through phonological decoding and self-teaching: Implications for dyslexia. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1634). http://dx.doi.org/10.1098/rstb.2012.0397.