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The Effect of Orthographic Depth on Letter String Processing: The Case of Visual Attention Span and Rapid Automatized Naming

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Abstract

The present study investigated whether orthographic depth can increase the bias towards multi-letter processing in two reading-related skills: visual attention span (VAS) and rapid automatized naming (RAN). VAS (i.e., the number of visual elements that can be processed at once in a multi-element array) was tested with a visual 1-back task and RAN was measured in a serial letter naming task that introduced a novel manipulation (some letter sequences formed frequent words). Spanish-Basque and French-Basque bilingual children were tested at early (30 children in 1st and 2nd grade), and more advanced (24 children in 3rd, 4th and 5th grade) stages of reading acquisition to investigate whether they would be differently biased towards multi-letter processing due to reading in two shallow (Spanish, Basque), or a deep and a shallow (French, Basque) orthography. The French-Basque bilinguals, who read in a deep orthography, were expected to rely on larger orthographic units in reading and thus to be more biased towards multi-letter processing in both tasks. This was expected to be reflected by: a) a uniform distribution of attention across letter strings in the VAS task, and b) a greater interference of the embedded words on letter-by-letter naming in RAN, leading to longer naming times. The expected group differences were observed in the more advanced readers, with French-Basque bilinguals showing a wider distribution of VAS across letter strings and longer naming times in RAN.

Keywords: orthographic depth, multi-letter processing, visual attention span, rapid automatized naming, cross-linguistic

The Effect of Orthographic Depth on Letter String Processing: The Case of Visual Attention Span and Rapid Automatized Naming

The first step to literacy consists in acquiring the mappings between written and spoken language. In alphabetic orthographies the complexity of this step partly depends on orthographic depth, meaning the consistency with which the graphemes of the written language are mapped to the phonemes of the spoken language when reading, and in the opposite direction when writing (Frost & Katz, 1989, 1992).

Focusing on the mapping of written to spoken language (spelling-to-sound mapping), the concept of orthographic depth encompasses two aspects: the complexity and the reliability of grapheme-to-phoneme mappings (Schmalz, Marinus, Coltheart, & Castles, 2015). Learning to read in shallow orthographies, like Spanish or Basque, involves learning mostly simple grapheme-to-phoneme mappings. In most cases, single-letter graphemes correspond to phonemes (e.g., in Spanish, the letter “t” is always pronounced as the phoneme /t/), and there are few cases in which accurate mapping depends on neighbouring letters (e.g., in Spanish, “c” followed by “h” is a digraph that is pronounced /tʃ/, “c” followed by “a”, “o”, “u” or other consonants is pronounced /ˈk/, and “c” followed by “e” or “i” is pronounced /θ/). In deeper orthographies, like French or English, learning to read involves grasping more complex grapheme-to-phoneme mappings. Examples of this complexity include the higher number of mappings between multi-letter graphemes and phonemes (e.g., in French “ou”-/u/, “eau”-/o/, “aie”-/ɛ/,“aient”-/ɛ/, “ph”-/f/), and the more common dependence of accurate mapping on factors such as: neighbouring letters, or letter position within the word (e.g., in French many letters are not pronounced at the end of a word). The increased complexity of grapheme-to-phoneme mappings in deeper orthographies, leads readers to rely on processing more letters, or larger orthographic units, in order to read accurately (Ziegler & Goswami, 2005). However, this strategy is fully successful only when these mappings are also reliable. In Spanish and Basque, grapheme-to-phoneme mappings are reliable and maintained within different lexical units. For the vast majority of words this is also the case in French (exceptions exist, e.g., “monsieur”), but not in English, as showcased by the classical example of the pronunciation of “pint” as compared to “mint” and “hint”. As a result of this unreliability, errors when reading in English may occur even after the correct grapheme-to-phoneme mappings have been acquired, since in many cases lexical information is necessary for correct pronunciation.

This study focuses on orthographies in which grapheme-to-phoneme mappings are reliable, but differ in complexity. The aim is to investigate whether acquiring a writing system with complex grapheme-to-phoneme mappings, that leads the reader to rely on larger orthographic units, can favor simultaneous multi-letter processing even in non-reading tasks. Previous literature provides evidence that the effects of orthographic depth can be observed in reading (Ellis et al., 2004; Sprenger-Charolles, Siegel, Jiménez, & Ziegler, 2011; Ziegler & Goswami, 2005). The present study takes the novel approach of studying whether the effect of orthographic depth extends to two skills previously linked to reading ability, but that do not directly involve reading: the visual attention span and rapid automatized naming of letters.

The visual attention span (VAS) refers to the number of elements within a multi-element array that can be processed simultaneously (within a single fixation) (Bosse, Tainturier, & Valdois, 2007), and reflects aspects of visual short term memory and visual processing speed (Lobier, Dubois, & Valdois, 2013), independently of phonological processing (Bosse & Valdois, 2009; but also see Ziegler, Pech-Georgel, Dufau, & Grainger, 2010). The implication of VAS skills in reading development has been demonstrated in both shallow and deep orthographies (Bosse et al., 2007; Bosse & Valdois, 2009; Germano, Reilhac, Capellini, & Valdois, 2014; Lallier, Donnadieu, & Valdois, 2013; Valdois et al., 2014; van den Boer, de Jong, & Haentjens-van Meeteren, 2013). Nevertheless, the aspect of multi-element processing represented by VAS skills, could be of particular significance when at the first stage of reading development it is essential to process larger orthographic units, as is the case in deeper orthographies.

Supporting this view, cross-linguistic studies have demonstrated differences, both in VAS skills and in their implication in reading, that are linked to orthographic depth. More specifically in a study with adult monolingual readers (Awadh et al., 2016), VAS skills were found to correlate with reading skills for readers of French (a deeper orthography), but not for readers of Spanish (a more shallow orthography). Another study investigated letter string processing in English monolingual adults, and in bilingual adults who could also read in the shallow Welsh orthography (English-Welsh bilinguals). The results demonstrated that the latter group showed a disadvantage in rapid processing of multiple letters. This disadvantage was interpreted as a result of the bilingual group´s experience reading in a more shallow orthography, that lead to a decrease in the degree of reliance on larger orthographic units in reading (Lallier, Carreiras, Tainturier, Savill, & Thierry, 2013). These studies either tested monolinguals of different languages, or compared monolingual to bilingual participants. Only one study has previously compared the VAS skills of bilingual participants reading in a common shallow (Basque), and either a second shallow (Spanish), or deeper (French) orthography (Lallier, Acha, & Carreiras, 2016). This previous study demonstrated marginal differences between the two groups of bilinguals on their VAS skills in a group of early readers. These marginal differences indicated that French-Basque bilingual children had a wider distribution of visual attention across letter strings, compared to Spanish-Basque bilingual children (Lallier et al., 2016). The present study aims to corroborate and clarify the previous findings regarding the effect of orthographic depth on the VAS skills of bilingual populations, and to investigate possible effects of orthographic depth on rapid automatized naming (RAN).

RAN is indexed by the speed at which an individual can sequentially name a set of visual stimuli (e.g., colours, images of familiar objects, letters), and is also related to reading abilities across orthographies differing in orthographic depth (Fleury & Avila, 2015; Furnes & Samuelsson, 2011; Georgiou, Papadopoulos, Fella, & Parrila, 2012; Holopainen, Ahonen, & Lyytinen, 2001; Lafrance & Gottardo, 2005; Lervåg & Hulme, 2009; Manis, Seidenberg, & Doi, 1999; Moll et al., 2014; Plaza & Cohen, 2003). Although the sub-processes that underlie the RAN-reading relation are debated (for a review see Norton & Wolf, 2012), we suggest that there is a degree of overlap between the processes involved in performing the VAS and the RAN tasks, and that both tasks involve simultaneous multi-element processing.

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

The present study investigates the hypothesis that orthographic depth influences VAS and RAN skills. Both individuals at early and more advanced stages of reading acquisition are included, assuming that the bias towards processing larger orthographic units should increase during reading development, and reflect the shift from sequential decoding of letters to whole word processing (Frith, 1985; Share, 1995). Under this assumption, differences in multi-letter processing abilities attributed to orthographic depth would be more prominent in advanced readers. Moreover, a cross-linguistic approach is taken, studying two groups of bilinguals (i.e., Spanish-Basque and French-Basque bilinguals) in their common language (i.e., Basque). This approach circumvents some methodological limitations of cross-linguistic studies in monolinguals (stimuli choice, language of testing) and offers the additional advantage of the geographical and cultural proximity of these two populations. Regarding language proximity it should be noted that Spanish and French are both Romance languages with many similarities, while Basque is an isolated language, descendant of Pre-Indo-European languages (for a review on Basque see Laka, 1996). However, at the level of grapheme-phoneme mappings there is a large overlap between Basque and Spanish.

As aforementioned, both the Spanish and Basque orthographies are based on reliable and simple grapheme-phoneme mappings, while French is based on mainly reliable but more complex grapheme-phoneme mappings. Thus, reliance on small orthographic units should suffice for Spanish-Basque bilinguals to read accurately in both languages. On the other hand, when reading in French, French-Basque bilinguals must rely on larger orthographic units. The size of the orthographic units used when reading in Spanish or French are expected to affect reading or reading-related skills of these bilinguals in their other language, meaning Basque, through transfer (Durgunoğlu, 2002; Lallier et al., 2016).

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

Method

Participants

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

Children were matched based on gender (all but one pair), chronological age, language background (see below) and two control measures: non-verbal intelligence and text reading fluency in their first language (L1). Language background matching criteria were based on questionnaires provided by the children´s legal tutors and included: the order of acquisition of their L1 and their second language (L2), the age of acquisition (AoA) of Basque, and the percentage of bilingual exposure (percentage of time exposed to a bilingual environment). The legal tutor of each child was informed about the techniques, duration and goals of the study, and provided written consent for the child´s participation.

As aforementioned, the two language groups (French-Basque and Spanish-Basque bilinguals) were matched on chronological age within both the younger (U = 123, Z = 0.44, p = .67, r = .08), and older (U = 59, Z = -0.75, p = .47, r = -.15) age groups. Regarding language background, the two language groups were matched on AoA of Basque in the younger (U = 116.5, Z = 0.56, p = .60, r = .10), and the older (U = 98, Z = 1.64, p = .11, r = .33) age groups, and on percentage of bilingual exposure in the younger (U = 61.5, Z = -1.44, p = .16, r = -.26), and older (U = 61.5, Z = 0.066, p = .96, r = .01) age groups. The younger French-Basque bilingual group reported a lower score on overall competence in Basque than the Spanish-Basque bilingual younger group (t = -3.41, df = 21.54, p = .003). On this measure, no difference was found for the older age groups (t = -0.28, df = 18.38, p = .78) (table 1). Information on the children's non-verbal intelligence and text reading fluency is provided in the results section (table 2).

<Insert Table 1 here>

Experimental Tasks

The tasks presented in this study were administered as part of a larger battery consisting of eight 45-minute sessions that were performed with the teachers´ permission, during school hours, and in a quiet room within the school. Tasks were carried out in four different orders, and the computer-based tasks were administered using Presentation ®. In this study, the focus is on two cognitive paradigms of interest including a task measuring VAS abilities (a visual 1-back task) and tasks measuring RAN skills. A non-verbal intelligence task and a measure of text reading in the L1 and L2 were used as control tasks. All tasks, except text reading in Spanish or French, were administered and performed in Basque.

Cognitive tasks of interest.

Visual 1-back task (VAS). VAS skills were assessed with a visual 1-back paradigm (Lallier et al., 2016). Stimuli were created using 13 consonants present in the Basque, Spanish and French alphabets (B, D, F, G, H, K, L, M, N, P, R, S, T). The consonant strings did not include grapheme clusters corresponding to Basque, Spanish or French phonemes and were not word skeletons of these languages (e.g., T L F N S, for "teléfonos" in Spanish). Letters were not repeated in a single letter string. Two different tasks were created depending on the children´s grade, as preliminary piloting showed that five-consonant strings were too difficult to process for younger children. Therefore, a task including 92 four-consonant strings, and a task including 104 five-consonant strings, were designed for the younger (1st and 2nd grade), and the older age group (3rd, 4th and 5th grade) respectively. Consonant strings were presented on a white screen in black upper-case Arial font and children were seated 70 cm away from the screen. Stimulus width varied between 4.24° and 4.4° of visual angle (four-consonant task), or 5.3° and 5.55° of visual angle (five-consonant task), and the centre-to-centre distance between each adjacent letter was 1.2° to minimize lateral masking effects. At the start of each trial, a central fixation point was displayed for 1000 ms, followed by the centred consonant string for 200 ms. The consonant string was followed by a white screen lasting 100 ms, and then a single letter (target), appearing below the median horizontal line. Target letters were presented in red with a bold-italic font, to reduce visual similarity with the preceding letter strings. Children were instructed to respond as fast as possible by pressing either: a) the “Alt Gr” key (on the right), when the target letter was present in the previously presented consonant string, or b) the “Alt” key (on the left), when the target letter was absent. The target disappeared after the child’s response, and a screen with a question mark in the centre was presented, until the experimenter pressed the left mouse button to initiate the next trial. Trial order was randomized.

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

Single letter identification. This task was used to assess single element processing, as a control for multi-element processing, measured in the visual 1-back task. In each trial, a single consonant was presented in the centre of the screen at five different brief presentation durations (33, 50, 67, 84 and 101 ms). The consonant was followed by a 50 ms mask and children were asked to name the previously presented consonant. All consonants used in the VAS task were included in this task. A weighted sum, based on the accuracy of letter identification at each presentation duration was computed (accuracy at 33 ms * 5 + accuracy at 50 ms * 4 + accuracy at 67 ms ∗ 3 + accuracy at 84 ms ∗ 2 + accuracy at 101 ms, Awadh et al., 2016).

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

RAN task was always performed last, in order to avoid that any child who noticed the presence of Basque words would be affected when performing the other RAN tasks.

Control tasks.

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

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

Data Analyses

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

Results

Control Tasks

The ANOVA on the age-standardised non-verbal intelligence scores showed no significant main effect or interaction (*ps* > .70), indicating that the French-Basque and Spanish Basque bilinguals were matched on this measure. The ANOVA on log-transformed reading fluency in the L1 (French or Spanish) also showed no effect or interaction with language group (*ps* > .29), indicating that the two language groups were matched on their reading skills in their L1. However, there was an effect of grade ($F(1,48) = 49.40$, $p < .001$, $\eta_p^2 = .51$), with the older age group being more fluent than the younger age group. The ANOVA on log-transformed reading fluency in Basque (L2) showed a main effect of language group ($F(1,48) = 21.77$, $p < .001$, $\eta_p^2 = .31$) and no interaction with age group ($p > .53$), indicating that overall the Spanish-Basque bilingual group read more Basque words per second than the French-Basque bilingual group. Moreover, the main effect of age group ($F(1,48) = 40.54$, $p < .001$, $\eta_p^2 = .46$) indicated that the older age group overall read more words per second in Basque than the younger age group (table 2).

<Insert Table 2 here>

Experimental Tasks

VAS-related tasks.

Single letter identification. No effect of language group was found on the weighted sum, calculated based on performance on the single letter identification task, in the younger (U = 124, Z = 0.48, p = .65, r = 0.09) or the older children (U = 71, Z = -0.06, p = .97, r = -.01). Subsequently, differences between the two groups on the visual 1-back task cannot be attributed to differences in single letter processing (table 3).

<Insert Table 3 here>

Four consonant visual 1-back (younger age group). D-prime sensitivity scores on the VAS task are presented in table 4 for both the four and five-consonant tasks. An odd–even split was used to determine the split-half reliability of the average d-prime, yielding a coefficient of 0.72. In the younger group, data were transformed to improve the distribution and homogeneity of variance by moving all scores within the positive range (by adding the absolute value of the smallest score to all the data), and then applying a square root transform. Regarding the visual 1-back task, in the younger age group there was no significant effect of language group (F(1,26) = 2.94, p = .10, η_p^2 = .10) on d-prime sensitivity. There was a significant effect of position (F(3,78) = 5.50, p = .006, η_p^2 = .17), but no language group by position interaction (F(3,78) = 1.19, p =.32, η_p^2 = .04). The post hoc on position indicated that d-prime sensitivity was significantly higher on position 1 than on position 4 (t = 3.43, df = 27, p = .01, r^2 = .30), and significantly higher on position 2 than on position 4 (t = 2.94, df = 27, p = .03, r^2 = .24), while the differences between sensitivity on other positions were not significant (ps > .11) (see figure 1).

<Insert Table 4 here>

<Insert Figure 1 here>

Five-consonant visual 1-back (older age group). In the older age group there was no effect of language group ($F(1,22) = 1.49$, $p = .24$, $\eta_p^2 = .06$), but there was a significant effect of position ($F(4,88) = 8.85$, $p < .001$, $\eta_p^2 = .29$), and a language group by position interaction ($F(4,88) = 2.99$, $p = .04$, $\eta_p^2 = .12$). The post hoc tests did not show differences between the French-Basque and Spanish-Basque bilingual groups on each individual position (*ps* > .24). For the French-Basque bilingual group, d-prime scores were similar across all positions (*ps* > .49). However, for the Spanish-Basque bilingual group, d-prime scores were significantly higher on position 2 than on position 4 ($t = 10.61$, $df = 11$, $p < .001$, $\eta_p^2 = .91$), and marginally higher on position 2 than on position 5 ($t = 3.71$, $df = 11$, $p = .06$, $\eta_p^2 = .56$), while they were also higher on position 3 than on positions 4 ($t = 9.21$, $df = 11$, $p < .001$, $\eta_p^2 = .89$) and 5 ($t = 5.47$, $df = 11$, $p = .004$, $\eta_p^2 = .73$) (see figure 2). No other differences were significant (*ps* > .57). Overall, the results revealed that d-prime sensitivity was stable across all positions for the French-Basque bilingual group, while this was not the case in the Spanish-Basque bilingual group.

<Insert Figure 2 here>

RAN tasks.

Descriptive statistics on RAN performance (errors and speed) are presented in table 5. There were no differences regarding errors during the RAN tasks in the older (*ps* > .15) or the younger (*ps* > .12) age group (indicating that differences in reaction times are not related to a speed-accuracy trade-off). In naming speed, there was a marginal age group effect ($F(1,48) = 3.92$, $p = .05$, $\eta_p^2 = .08$), a significant language group effect ($F(1,48) = 98.06$, $p < .001$, $\eta_p^2 = .67$) and a significant task effect ($F(1,96) = 4.01$, $p = .02$, $\eta_p^2 = .08$). All these effects were also part of a triple interaction described below. The age group by language group interaction was not significant ($F(1,48) = 0.08$, $p = .78$, $\eta_p^2 = .002$). The age group by task ($F(1,96) =$

7.63, $p = .003$, $\eta_p^2 = .14$), language group by task ($F(1,96) = 4.75$, $p = .02$, $\eta_p^2 = .09$) and age group by language group by task ($F(1,96) = 6.77$, $p = .005$) interactions were significant.

<Insert Table 5 here>

The post hoc tests (see footnote 1) indicated that the younger children of the French-Basque bilingual group performed similarly on all the RAN tasks (*ps* > .58). The younger children of the French-Basque bilingual group also performed both the consonant RAN ($t = 3.05$, $df = 19.97$, $p = .01$, $\eta_p^2 = .32$) and the non-word RAN ($t = 3.12$, $df = 15.29$, $p = .01$, $\eta_p^2 = .39$) tasks more slowly than the older French-Basque bilingual group, but performed the word RAN task ($t = -1.94$, $df = 22.29$, $p = .07$, $\eta_p^2 = .14$) marginally faster than the older French-Basque bilingual group. The older children in the French-Basque bilingual group performed both the consonant and non-word RAN at a similar speed ($t = 2.17$, $df = 10$, $p = .22$, $\eta_p^2 = .32$), while performance on the word RAN task was slower than in both of these tasks (consonant RAN-word RAN comparison: $t = -3.84$, $df = 10$, $p = .02$, $\eta_p^2 = .60$, non-word RAN-word RAN comparison: $t = -4.88$, $df = 10$, $p = .004$, $\eta_p^2 = .70$).

The post hoc tests also indicated that the younger children of the Spanish-Basque bilingual group performed the consonant RAN at a similar speed to the non-word RAN ($t = 2.14$, $df = 14$, $p = .25$, $\eta_p^2 = .25$) but more slowly than the word RAN task ($t = 3.72$, $df = 14$, $p = .01$, $\eta_p^2 = .50$). The non-word and the word RAN task were performed at a similar speed ($t = 1.38$, $df = 14$, $p = .19$, $\eta_p^2 = .12$). The younger children of the Spanish-Basque bilingual group also performed all RAN tasks more slowly than the older children of the Spanish-Basque bilingual group (consonant RAN: $t = 4.91$, $df = 23.10$, $p < .001$, $\eta_p^2 = .51$, non-word RAN: $t = 5.60$, $df = 24$, $p < .001$, $\eta_p^2 = .57$, word RAN: $t = 4.10$, $df = 21.34$, $p < .001$, $\eta_p^2 = .44$). The older children of the Spanish-Basque bilingual group performed all the RAN tasks at a similar speed (*ps* > .53). Lastly, the Spanish-Basque bilinguals performed all RAN tasks overall more quickly than the French-Basque bilinguals of the same age group (*ps* $< .05$) (see figure 3).

<Insert Figure 3 here>

Overall, in most cases the older age group performed the RAN tasks faster than the younger age group and the French-Basque bilingual group performed all RAN tasks more slowly than the Spanish-Basque bilingual group. Of particular interest is the pattern of performance found for the word RAN task in the French-Basque bilingual group: while there was no effect of the manipulation in the younger age group, in the older age group the word RAN task was performed more slowly than the two other RAN tasks by the French-Basque bilingual group. This pattern of results was absent in the Spanish-Basque bilingual group.

Correlations between RAN and VAS performance.

Correlations were performed between the average d-prime scores on the VAS task and the reaction times of the RAN task. Although the latter were not normally distributed, correlations performed using the normally distributed, log transformed data, resulted in the same patterns of significance. Thus, correlations and plots present the untransformed data (see table 6 and figure 4) for simplicity. No significant correlations were found between performance on any of the RAN tasks and the VAS task, neither in the Spanish-Basque bilingual group (*ps* $> .24$), nor the French-Basque bilingual group (*ps* $> .16$). However, note that the direction of the correlations in the French-Basque bilingual group indicated that: better VAS skills related to better performance on RAN in the consonant and non-word RAN tasks, while the opposite was true in the word RAN task (possibly because in the latter, better multi-element processing resulted in easier identification of the embedded words).

<Insert Table 6 here>

<Insert Figure 4 here>

Discussion

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

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

Interestingly, despite the lack of significant differences in the younger group, there were indications that in both tasks multi-letter processing was relied on to a greater extent in the French-Basque bilingual group. Regarding VAS skills, the pattern of results demonstrated, even in the younger children, higher average d-prime sensitivity for the

French-Basque as compared to the Spanish-Basque bilinguals. Furthermore in the RAN task including words, the experimenter reported that even in the younger group, only children from the French-Basque bilingual group read out loud some of the words hidden in the stimulus board (4 of the 15 children of the younger group and 8 of the 11 children of the older group of French-Basque bilinguals).

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

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

Concerning the RAN results, the insertion of high frequency Basque words in the task had a detrimental effect only in French-Basque bilinguals of the older group. The slower naming scores of the French-Basque bilinguals in this task can be interpreted as the manifestation of a processing cost resulting from lexical access to the Basque words. According to this hypothesis, French-Basque bilingual children in the older group must have processed more letters in parallel when performing the task than their Spanish-Basque peers, thus capturing the letters that composed the Basque words as a whole. These results confirm that the effects of orthographic depth can be observed in tasks not directly involving reading (Lallier et al., 2016; Lallier & Carreiras, 2017). Furthermore, the results indicate that there is a degree of multi-letter processing in the RAN that can be enhanced under certain conditions (in this case the insertion of lexical units). This supports previous studies suggesting that there is an aspect of multi-element processing in RAN (Bowers, 1995; Logan et al., 2011; Logan & Schatschneider, 2014; Protopapas et al., 2013), and could explain the previously reported correlations between VAS and RAN performance (van den Boer et al., 2014, 2015).

One of the issues that arise from the RAN results is that of the slower overall performance of the French-Basque bilingual group. Two factors could explain this result: a) while the two groups were matched on most language background measures, Spanish-Basque bilinguals were overall more fluent in Basque text reading, b) the degree of overlap in the pronunciation of letter names is almost complete between Spanish and Basque but smaller between French and Basque (e.g., the letter “H” is pronounced /ˈatʃe/ in both Spanish and

Basque but /aʃ/ in French), thus increasing the difficulty of the task for the French-Basque bilinguals. Notably, this overall difference should not result from other group differences, since age, non-verbal intelligence and reading in the L1 were matched. Moreover, this should not jeopardize the main result, that the older group of French-Basque bilinguals was slower on the word RAN as compared to the other RAN tasks.

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

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

Another aspect to consider when examining the results in the word RAN task is that of individual differences in RAN processing. The hypotheses and results support that RAN performance reflects multi-letter processing and that the number of letters that can be processed is influenced by orthographic depth. If this is the case, reading experience in deep orthographies should increase the bias towards multi-letter processing, while reading experience in shallow orthographies should decrease this bias. For the Spanish-Basque bilinguals, reading more in either of the two shallow orthographies would not create heterogeneity in this bias, since reading in either of the two orthographies should decrease the bias towards multi-letter processing. However for French-Basque bilinguals, children who read more in the deep French orthography would be more strongly biased towards multi-letter processing than children who read more in the shallow Basque orthography. Therefore within the French-Basque bilinguals, the degree to which each individual is biased towards multi-letter processing could be more variable and depend on the time spent reading in each language (see footnote 2). Differences in the degree of bias towards multi-element processing as a result of the amount of time spent reading in a deep or shallow orthography would also be expected to influence the multi-element processing bias reflected by VAS skills.

The present study explored the effect of orthographic depth on multi-letter processing in two tasks including visual letter processing: VAS and RAN. These skills were evaluated in two groups of bilingual children, one group learning to read in two shallow orthographies (Spanish-Basque) and the other learning to read in a deep and a shallow orthography (French-Basque). The results indicate that reading in the deep French orthography lead to a larger bias towards the use of multi-letter processing in both the VAS and the word RAN tasks in more advanced readers (3rd, 4th and 5th grade). Further research on larger samples is needed to test the degree to which orthographic depth and bilingual reading experience can affect the bias towards multi-letter processing depending on the relative time spent reading in each language. Cross-linguistic studies at this level can provide information regarding the difficulties faced by bilingual children learning to read in two languages, but also regarding the tools they have at hand to compensate for these difficulties.

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Footnotes

Footnote 1. The assumption of normality was violated in two of the sub-conditions and could not be corrected by transforming the data. Therefore all post-hoc comparisons were also performed using the Mann-Whitney U and Wilcoxon signed-rank tests and adjusting for multiple comparisons. The pattern of significance remained the same so the parametric ANOVA and post hoc comparisons are presented for simplicity.

Footnote 2. While the information necessary to answer this question was available for the sample of this study, the results were not conclusive due to the small variability of reading experience in Basque for the French-Basque bilinguals.

Table 1

Descriptive statistics on age and language background measures of the older and younger Spanish-Basque and French-Basque bilinguals

		Younger		Older	
		Spanish-Basque	French-Basque	Spanish-Basque	French-Basque
Chronological age (years)	*M (SD)*	6.82 (0.47)	6.88 (0.41)	9.79 (0.98)	9.6 (1.2)
	Median	6.75	6.83	9.5	8.96
	Range	6.25 – 7.75	6.42 – 7.75	8.58 – 11.17	8.25 – 11.33
N° children L1 Basque		1	1	1	1
N° children L1 Spanish/French [a]		14	14	11	11
Basque AoA (years) [b]	*M (SD)*	2.13 (1.46)	2.32 (1.27)	2.25 (1.14)	3.58 (2.38)
	Median	3	3	3	3
	Range	0 – 5	0 – 3	0 – 3	0 – 10
% Bilingual exposure	*M (SD)*	31.54 (18.3)	26.79 (29.97)	19.75 (15.39)	29.27 (33.36)
	Median	25	15	27.2	20
	Range	10 – 80	0 – 100	0 – 40	0 – 80
Basque overall competence (out of 10)	*M (SD)*	7.25 (1.18)	5.52 (1.4)	7.14 (1.32)	7 (0.97)
	Median	7.5	5.5	7	6.75
	Range	5.25 – 9	3.5 – 7.25	5 – 9.5	5.75 – 8.75

Note. *M*: mean, *SD*: standard deviation. [a]. L1 Spanish for the Spanish-Basque and L1 French for the French-Basque bilingual group.

[b]. AoA=age of acquisition.

Table 2

Descriptive statistics on the non-verbal intelligence and text reading tasks for the younger and older Spanish-Basque and French-Basque bilinguals

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

Note. *M*: mean, *SD*: standard deviation.

Table 3

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

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

Note. *M*: mean, *SD*: standard deviation.

Table 4

Descriptive statistics on VAS sensitivity scores for the older and younger Spanish-Basque and French-Basque bilinguals

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

Note. *M*: mean, *SD*: standard deviation.

[c]. One participant from the Spanish-Basque group and their match from the French-Basque group were removed because the former was only pressing one response button.

Table 5

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

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

Note. *M*: mean, *SD*: standard deviation.

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

Table 6

Partial correlations between scores on the RAN and VAS tasks for each of the two language groups (Spanish-Basque and French-Basque bilinguals) including younger and older children

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

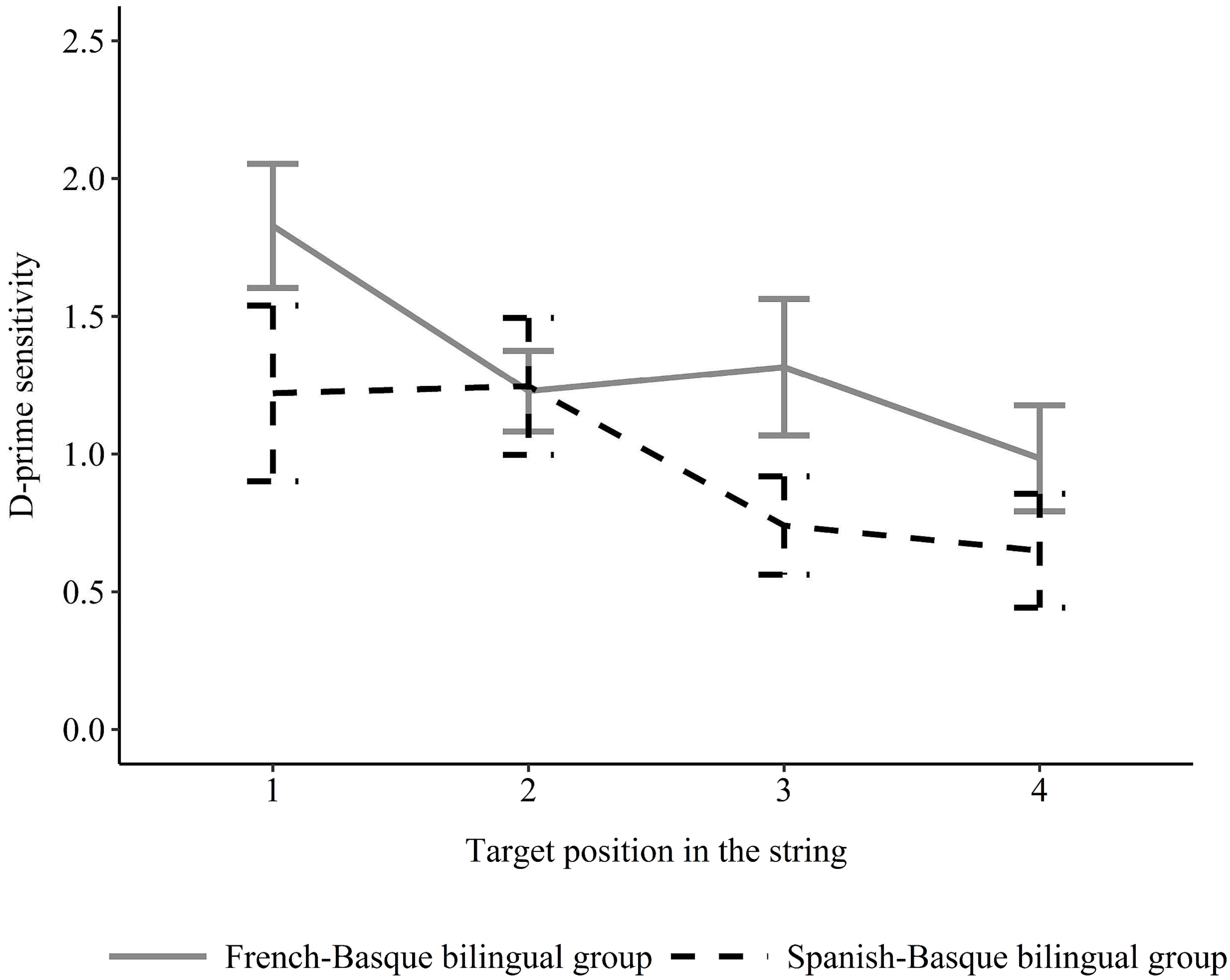
Figure Captions

Fig 1 D-prime sensitivity scores and standard error bars (1 *SE*) by position and language group for the four-consonant VAS task performed in the younger age group (1^{st} and 2^{nd} grade children)

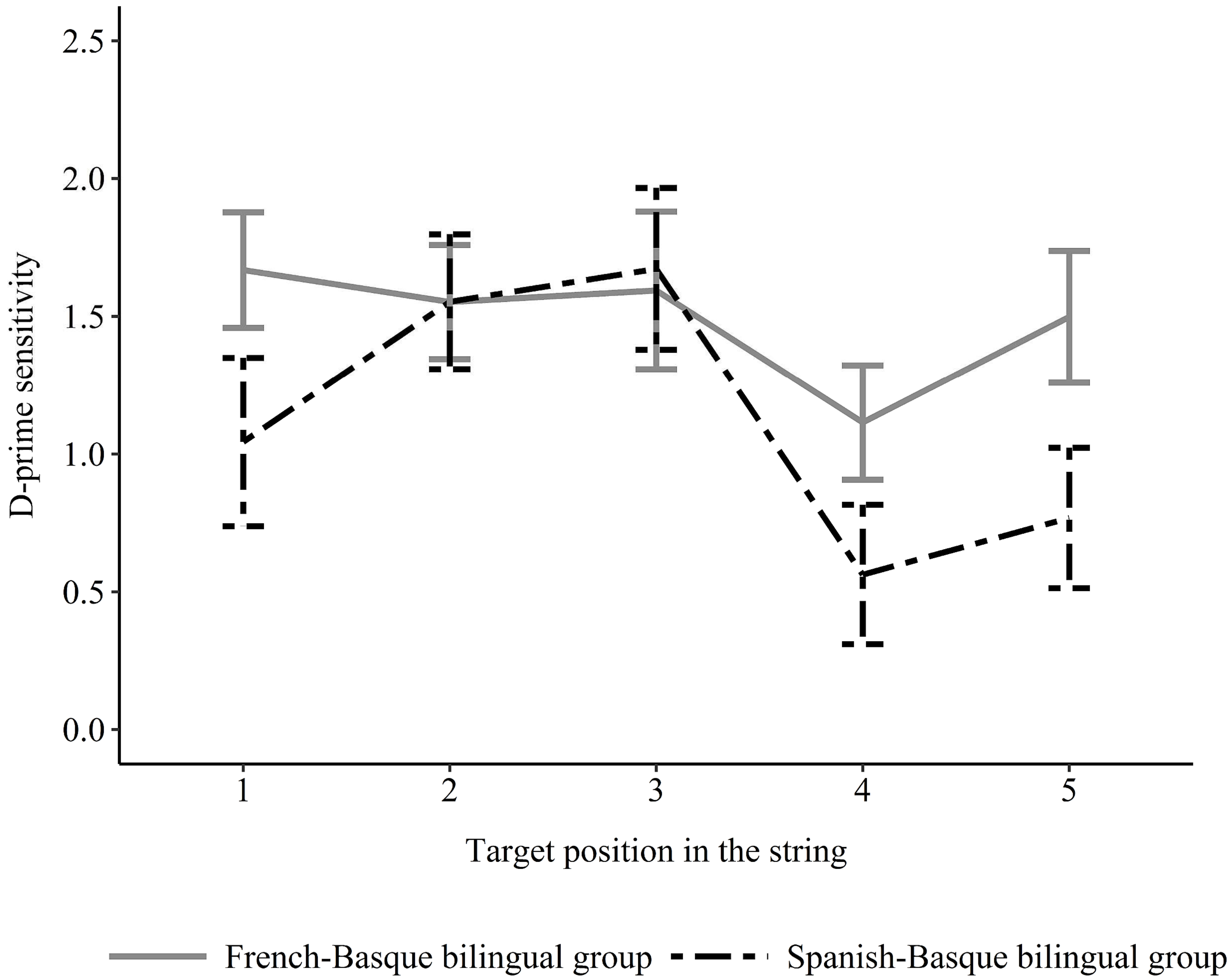
Fig 2 d-prime sensitivity scores and error bars (1 *SE*) by position and language group for the five-consonant VAS task performed in the older age group (3^{rd}, 4^{th} and 5^{th} grade children)

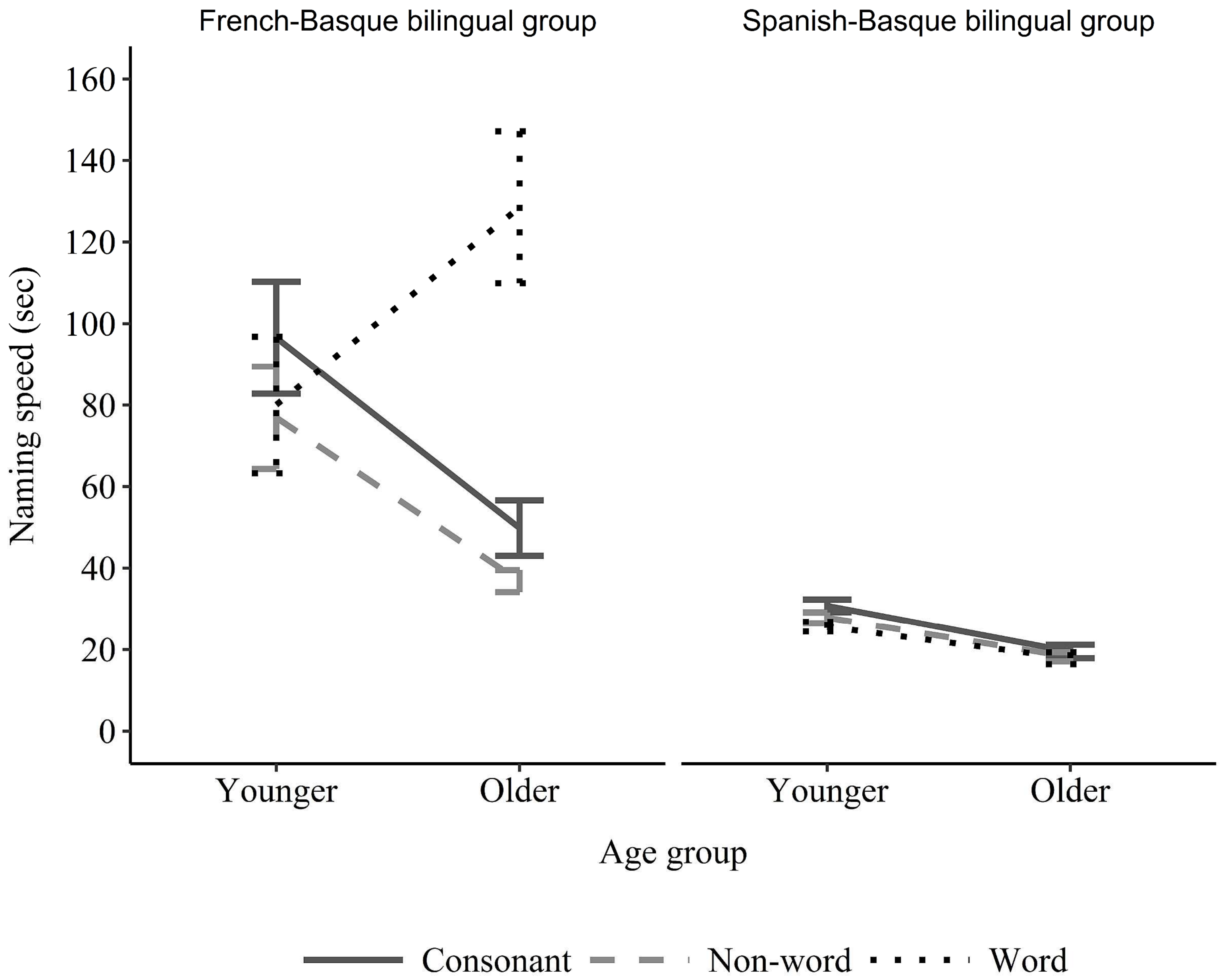
Fig 3 Mean speed of naming and standard error bars (1 *SE*) of performance on the RAN tasks by language group and by age group

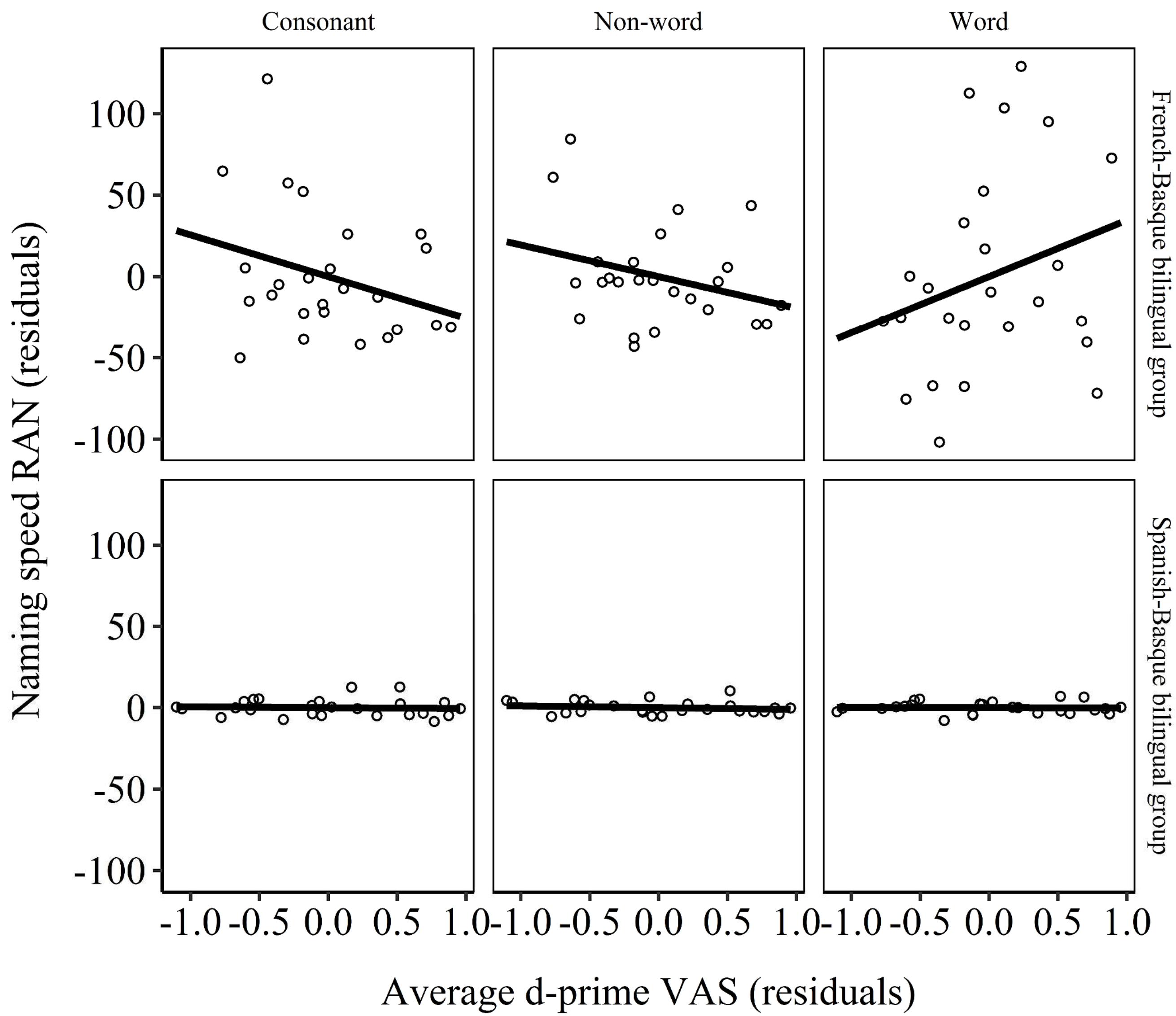
Fig 4 Plot of correlations between the residuals of RAN speed (sec) and average d-prime sensitivity (after controlling for chronological age and non-verbal intelligence) within each RAN task and language group



D-prime sensitivity
2.5
2.0
1.5
1.0
0.5
0.0
1
2
3
4
Target position in the string
French-Basque bilingual group
Spanish-Basque bilingual group


2.5
2.0
1.5
1.0
0.5
0.0
D-prime sensitivity
1
2
3
4
5
Target position in the string
French-Basque bilingual group
Spanish-Basque bilingual group


French-Basque bilingual group
Spanish-Basque bilingual group
Naming speed (sec)
160
140
120
100
80
60
40
20
0
Younger
Older
Younger
Older
Age group
Consonant
Non-word
Word


Consonant
Non-word
Word
French-Basque bilingual group
Spanish-Basque bilingual group
Naming speed RAN (residuals)
100
50
0
-50
-100
-1.0 -0.5 0.0 0.5 1.0
Average d-prime VAS (residuals)