# Title: Does the visual attention span play a role in the morphological processing of orthographic stimuli?

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Abstract

We investigated whether the link between visual attention span and reading is modulated by the presence of morphemes. Second and fourth grade children, with Basque as their first language, named morphologically complex and simple words and pseudowords, and performed a task measuring visual attention span. The influence of visual attention span skills on reading was modulated by the presence of morphemes in naming speed measures. In addition, fourth grade children with a larger visual attention span showed larger lexicality effects (pseudoword-word reading times) only for morphologically simple stimuli. Results are interpreted as support for the notion that both transparency and morphological complexity are important factors modulating the impact of VA span skills on reading.

*Keywords:* morphological processing, reading development, visual attention span

# Does the visual attention span play a role in the morphological processing of orthographic stimuli?

While reading, individuals can resort to two possible routes for word identification, which are characterised by the size of the orthographic grain used (Grainger & Ziegler, 2011). The coarse-grained route facilitates processing at the lexical level, optimizing word identification. The alternative fine-grained route reflects processing of multi-letter patterns at the sub-lexical level; allowing the identification and construction of relevant orthographic units of multi-letter graphemes, frequent letter combinations and morphemes. In the course of reading development, the use of these two routes, paired with the influence of language-specific orthographic constraints, gives rise to specific grapheme-to-phoneme mapping strategies. These strategies support the internalization of recurring letter patterns and their pronunciations, thus paving the way towards fluent reading.

Both the coarse and the fine grained routes of reading require parallel letter processing, which could be one of the mechanisms underlying the reported link between visual attention and reading (Bosse, Tainturier, & Valdois, 2007; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Vidyasagar & Pammer, 2010). Indeed, a current hypothesis in the literature is that good visual attention skills facilitate parallel processing of letter strings, improving orthographic processing, either at the lexical or sub-lexical level (Grainger, Dufau, & Ziegler, 2016). In line with this hypothesis are studies on the visual attention span (VA span), a measure of visual attention reflecting the number of distinct visual elements that can be processed simultaneously in a multi-element array (Bosse et al., 2007). Better VA span skills accompany better reading skills in reading development in various alphabetic orthographies (Bosse et al., 2007; Bosse & Valdois, 2009; Germano, Reilhac, Capellini, &

Valdois, 2014; Lobier, Zoubrinetzky, & Valdois, 2012; Onochie-Quintanilla, Defior, & Simpson, 2017; van den Boer, van Bergen, & de Jong, 2014).

Notably, a larger VA span has been particularly linked to processing multi-letter orthographic units, facilitating their recognition and internalization. More specifically, the VA span has been related to the acquisition of lexical orthographic representations (Bosse, Chaves, Largy, & Valdois, 2013) and to orthographic knowledge, spelling and copying skills (Bosse, Kandel, Prado, & Valdois, 2014; van den Boer, van Bergen, & de Jong, 2015). Additionally, a larger VA span favours reading accuracy of irregular words (for which whole-word processing is essential) more strongly than that of regular words or pseudowords (Bosse & Valdois, 2009). Finally, a reduced VA span has been associated with poor word – as opposed to pseudoword - reading abilities in certain developmental dyslexia profiles (Bosse et al., 2007; Peyrin et al., 2012; Peyrin, Démonet, N'Guyen-Morel, Le Bas, & Valdois, 2011; Valdois et al., 2003, 2014). Thus, the VA span likely modulates the degree to which essential orthographic grains are internalized during reading development.

Overall, these findings suggest that VA span abilities might significantly contribute to orthographic processing of letter strings, particularly during reading development when relevant orthographic units are yet to be internalized. In order to obtain a full picture of the role of VA span in reading acquisition across alphabetic orthographies, it is important to look for all the potential factors that could modulate this contribution. For example, research mentioned above suggests that the type of item to be read (real words versus pseudowords, or irregular versus regular words) modifies the strength of the contribution of VA span to reading. In the same vein, orthographic depth (the complexity and regularity of grapheme-to-phoneme mappings) was found to be a significant modulator of the VA span-reading relationship, with a stronger relationship for deep orthographies – that include irregular words and graphemes– than shallow orthographies (Lallier & Carreiras, 2018, for a review).

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

Studies on the effects of derivational morphology on reading in shallow orthographies show a “morphological benefit”: an advantage for reading items including sub-lexical morphemes over items that are morphologically simple. The benefit is attributed to the fact that morphemes act as a large sub-lexical grain or reading unit that is processed more easily than its constituent letters and graphemes (Burani, Marcolini, De Luca, & Zoccolotti, 2008; Burani, 2009). Interestingly, this morphological benefit is particularly evident when the coarse grain route is likely to fail, since it occurs when naming morphologically complex pseudowords (Angelelli, Marinelli, & Burani, 2014; Burani et al., 2008; Burani, Marcolini, &

Stella, 2002; Suárez-Coalla & Cuetos, 2013; Traficante, Marcolini, Luci, Zoccolotti, & Burani, 2011), or low frequency words (Angelelli et al., 2014; Burani et al., 2008; Marcolini, Traficante, Zoccolotti, & Burani, 2011; Traficante et al., 2011), as well as for less expert and dyslexic readers who have not fully developed their lexical reading procedure (Burani et al., 2008; Marcolini et al., 2011; Suárez-Coalla & Cuetos, 2013).

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

# Methods

## Participants

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

## Morphological Processing Task: Naming

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

Regarding the morphologically complex word stimuli, although morphological facilitative effects are more prone to appear in low frequency words (Deacon, Whalen, &

Kirby, 2011), the high productivity of Basque allows Basque children to benefit from suffixes present in high frequency words even from third grade, at least with regard to inflectional morphology (Acha et al., 2010). Based on previous evidence on the potential impact of both stem and word frequency on reading (Carlisle & Katz, 2006; Deacon et al., 2011; Mann & Singson, 2003) we decided to include both low and high frequency words (half of each set of words: morphologically complex and simple). Moreover, half of the morphologically complex words (within both the high and low word frequency stimuli), had high stem frequency while the other half had low stem frequency. Given that this is the first study on developing readers of Basque naming aloud derived words, we performed an analysis on the morphologically complex words in order to investigate the effects of word and stem frequency on reading speed and accuracy.

Both for the word and the pseudoword stimuli, several productive suffixes were selected ("*gile*", "*te*", "*dun*", "*le*", "*koi*", "*kari*", "*kor*", "*ti*", "*keta*", "*txo*", "*tsu*", "*keria*", "*lari*", "*zain*", "*ar*", "*kera*", "*tza*", "*tegi*", "*go*"), in order to increase the bias towards processing the constituent morphemes of the items (Bertram, Schreuder, & Baayen, 2000). Morphologically simple pseudowords were constructed aiming to minimise orthographic neighbourhood size (N) and were thus the only condition in which stimuli had on average fewer orthographic neighbours. However, due to the high productivity of Basque morphemes and to the greater importance of controlling stem frequency, length and bigram variables over N, we could not minimise orthographic neighbourhood size to the same degree for the morphologically complex pseudowords. Lists were matched as much as possible on first sound variability. Finally, word frequency and stem frequency were matched across conditions with the exception of stem frequency for high stem frequency words that could not be matched across the high and low word frequency conditions (it should be noted that the mean stem frequency gap in high frequency words was 5.8 vs. 3.6 while in the low frequency words it was 4.9 vs. 3.8). All stimuli and descriptive statistics on relevant variables are presented in Appendix A.

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

## Visual Attention Span: Visual one-back task

VA span skills were assessed with a visual 1-back paradigm (Lallier, Acha, & Carreiras, 2016). Stimuli were created using 13 consonants present in the Basque and Spanish alphabet (B, D, F, G, H, K, L, M, N, P, R, S, T). The consonant strings did not include grapheme clusters corresponding to Basque or Spanish 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. Stimuli included 104 five-consonant strings that 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 5.3° and 5.55° of visual angle and the centre-to-centre distance between each adjacent letter was 1.2°, to minimize lateral masking effects. In each trial, a central fixation point was displayed for 1000 ms, followed by the centred consonant string for 200 ms. The consonant string was followed by a white screen lasting 100 ms and 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 the “Alt Gr” key (on the right) when the target letter was present in the previously presented consonant string, and the “Alt” key (on the left) when it was absent. The target disappeared after the child’s response, and a screen with a question mark in the centre was presented until the experimenter pressed the left mouse button to initiate the next trial. Trial order was randomized.

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). At the beginning of the task five practice trials were provided with feedback. Accuracy was recorded for each trial based on which an individual VA span score (average d-prime sensitivity index) was calculated.

## Control Tasks

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

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

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

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

**Single letter processing.** An individual index of single, as opposed to multi-letter processing (measured in the visual one-back task) was calculated with a task including all consonants used in the VA span task. In each trial a single consonant was presented in the centre of the screen at 5 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. A weighted sum of performance on the task (score at 33 ms * 5 + score at 50 ms * 4 + score at 67 ms * 3 + score at 84 ms * 2 + score at 101 ms, Awadh et al., 2016) was used.

## General Procedure

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

## Data Analyses

Overall performance on the control tasks and VA span was compared between grades using either Welch´s t-test or Wilcoxon signed-rank tests. Naming accuracy and naming speed on accurate trials were analysed using logistic and linear mixed effects models respectively, with participants and items as crossed random effects (Baayen, Davidson, & Bates, 2008; Jaeger, 2008, lme4 package: Bates, Mächler, Bolker, & Walker, 2014). Mixed models were selected both in order to use similar methods for the analysis of naming accuracy and speed (high accuracy scores were more suited to a logistic mixed models analysis than to an ANOVA), and secondly due to the large individual variability in naming speed in early readers that can be better accounted for using mixed models. P-values were computed based on the Satterthwaite approximation for linear mixed models (lmerTest package: Kuznetsova, Bruun Brockhoff, & Haubo Bojesen Christensen, 2014) and based on the normal approximation for logistic models. Hochberg corrections were applied for multiple-comparisons and post hoc comparisons were performed using the lsmeans package (Lenth, 2016).

# Results

## General comparisons

Comparisons between children of the 2nd and 4th grade demonstrated a significant age difference ($t$ = -27.85, $df$ = 55, $p$ < .001), but no difference on age-standardised non-verbal intelligence ($t$ = 0.91, $df$ = 55, $p$ = .37), single letter processing ($U$ = 366.5, $Z$ = -0.62, $p$ = .54, $r$ = .08), nor VA span skills ($t$ = 0.09, $df$ = 53, $p$ = .93). Children in 4th grade also had greater vocabulary knowledge ($t$ = -5.42, $df$ = 53, $p$ < .001) and tended to have better phonemic awareness skills ($U$ = 304.5, $Z$ = -1.68, $p$ = .09, $r$ = -.22) than children in 2nd grade (see table 1). An odd-even split was used to calculate split-half reliability of the phonemic awareness and vocabulary knowledge tasks. The correlations between individuals´ scores on odd and even trials were adjusted using the Spearman-Brown prophecy formula to approximate the reliability of the tests overall. For the phonemic awareness task this yielded a coefficient of 0.87 for the 2nd grade and a coefficient of 0.85 for the 4th grade. For the vocabulary knowledge task this yielded a coefficient of 0.85 for the 2nd grade and a coefficient of 0.79 for the 4th grade.

<Insert table 1 here>

**Naming Task**

Naming speed scores were cleaned by applying upper and lower cut-offs of 500 and 10000 ms and removing values further than 3.5 standard deviations from the mean by subject and condition[1]($n_{removed}$=14, 0.17%). Scores were subsequently log-transformed to approximate a normal distribution. For both the linear and logistic mixed models, categorical factors were coded as sum contrasts meaning that the intercept of the model represents the grand mean and the estimates corresponded to deviations from the grand mean for each level of the factor. Predicted scores based on the mixed models were produced using the effects package (Fox, 2003) in order to plot both predicted and original data.

**Morphological effects in naming.** The categorical factors of lexicality (factor levels coded as [pseudoword, word] [1,-1]), morphological complexity (factor levels coded as [simple, complex] [1,-1]), grade (factor levels coded as [2$^{nd}$ grade, 4$^{th}$ grade] [1,-1]), and their interactions were included in the models. In the accuracy analysis, log-transformed reaction times were also included as a continuous predictor (centred on 0), accounting for speed-accuracy trade-offs (Davidson & Martin, 2013). All linear models included random intercepts for subjects and items, as well as random slopes for subjects for morphological complexity and lexicality effects and their interaction. Convergence problems in logistic models lead to the simplification of the random effects, including only random intercepts for subjects and items[2]. Descriptive statistics of the data are provided in table 2. Further analysis of the differences between the two different types of morphologically complex pseudowords (stem + pseudosuffix, pseudostem + suffix), showed no effect of type of pseudoword or interaction with grade for either accuracy or naming speed (*ps* > .25) and is therefore not presented. The results of our additional analysis of the morphologically complex words (studying word and stem frequency effects) are briefly summarised in a separate section following our main analyses.

<Insert table 2 here>

***Naming accuracy.*** The analysis resulted in an effect of log-transformed reaction times (Intercept =3.59, $\beta$ = -1.60, $z$ = -9.89, $p$ < .0001), an effect of lexicality ( $\beta$ = -0.23, $z$ = -3.31, $p$ = .0009), an effect of morphological complexity ($\beta$ = -0.27, $z$ = -4.03, $p$ = .0001), and a grade by lexicality by morphological complexity interaction ($\beta$ = 0.13, $z$ = 2.43, $p$ = .015, figure 1).

Post hoc comparisons on the lexicality by morphological complexity interaction within each grade showed that an advantage in naming morphologically complex over morphologically simple items was present for *words* in the 2$^{nd}$ grade ($\beta$ = 0.86, $z$ = 3.34, $p$ = .0099), and for *pseudowords* in the 4$^{th}$ grade ($\beta$ = 0.75, $z$ = 3.46, $p$ = .006). Moreover, lexicality effects (the difference in word as compared to pseudoword naming accuracy) were marginal only for morphologically complex items in the 2$^{nd}$ grade (complex: $\beta$ = 0.68, $z$ = 2.66, $p$ = .07 ; simple: $\beta$ = 0.10, $z$ = 0.46, $p$ = .64), while in the 4$^{th}$ grade the opposite was true with significant lexicality effects only for morphologically simple items (complex: $\beta$ = 0.31, $z$ = 1.13, $p$ = .64 ; simple: $\beta$ = 0.75 , $z$ = 3.18, $p$ = .015).

<Insert Figure 1 here>

***Naming times.*** The analysis resulted in significant effects of lexicality (Intercept= 7.61, $\beta$ = 0.12, $t$ = 8.62, p < .0001) and grade ($\beta$ = 0.15, $t$ = 5.71, $p$ < .0001), indicating that children in both grades read words faster than pseudowords, and that children in 4$^{th}$ grade read overall faster than children in 2$^{nd}$ grade. There was also a marginal grade by lexicality interaction ($\beta$ = -0.01, $t$ = -1.82, $p$ = .07), suggesting a trend for larger lexicality effects in the 4$^{th}$ grade.

Although morphological complexity effects were not significant in naming times, we conducted an additional analysis on morphologically complex words to test the potential role of stem and word frequencies on reading fluency. Only naming speed was analysed since naming accuracy was at ceiling in both morphologically complex and simple words. We firstly tested all words (complex and simple) with morphological complexity, word frequency, grade and their interactions as categorical factors coded as sum contrasts. Factor levels were coded as described previously for morphological complexity and grade; for word frequency factor levels were coded as [high frequency, low frequency] [1,-1]. Random intercepts for subjects and items were also included, as well as random slopes for subjects for morphological complexity, word frequency, and their interaction. The analysis resulted in significant effects of word frequency (Intercept= 7.49, $\beta$ = -0.08, $t$ = -4.93, $p$ < .0001) and grade ($\beta$ = 0.16, $t$ = 6.00, $p$ < .0001). No other effects or interactions were significant (*ps* > .10).

We then focused on morphologically complex words only. The categorical factors grade, word frequency, stem frequency (factor levels coded as [high stem frequency, low stem frequency] [1,-1]) and their interaction were included as fixed factors in the mixed effects model. Random intercepts for subjects and items were also included, as well as random slopes for subjects for word frequency, stem frequency and their interaction. It should be noted that high stem frequency words could not be matched across the high and low word frequency conditions. The analysis resulted in significant effects of word frequency (Intercept= 7.50, $\beta$ = -0.08, $t$ = -3.14, $p$ = .003), stem frequency ($\beta$ = -0.07, $t$ = -2.74, $p$ = .009) and grade ($\beta$ = 0.16, $t$ = 6.43, $p$ < .0001). The effect of word frequency indicated that morphologically complex high frequency words were named faster than morphologically complex low frequency words. The effect of stem frequency showed that words with high frequency stems were named faster than those with low frequency stems. No interaction was found between these factors (*ps* > .23).

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

***Naming accuracy.*** The analysis of the accuracy data from the children in 2nd grade demonstrated a main effect of VA span (Intercept=3.34, $\beta = 0.77$, $z = 2.45$, $p = .0144$) indicating that a larger VA span was related to more accurate naming. The analysis of the accuracy data from the children in 4th grade showed no effects or interactions involving VA span skills (Intercept = 3.82, *ps* > .13).

***Naming times.*** The analysis of the naming speed data from the children in 2nd grade showed no effects or interactions involving VA span skills (Intercept = 7.75, *ps* > .26). The analysis of the naming speed data from the children in 4th grade demonstrated a significant interaction including VA span skills: the lexicality by morphological complexity by VA span interaction (Intercept = 7.46, $\beta = 0.025$, $t = 2.07$, $p = .0481$).

To interpret the interaction post hoc comparisons were used to test the significance of lexicality effects for morphologically simple and complex items at different values of VA span skills (ranging from the lowest scaled value of -0.88 to the highest value of 1.19). The tests showed that all lexicality effects (the comparison of pseudoword and word naming speed) were significant (*ps* < .0022). However, for morphologically complex items lexicality effects were similar across different values of VA span skills (e.g., $t_{(VA\ span=-0.88)} = 4.04$, $t_{(VA\ span=-0.48)} = 4.97$, $t_{(VA\ span=-0.08)} = 5.57$, $t_{(VA\ span=0.32)} = 5.15$, $t_{(VA\ span=0.72)} = 4.16$, $t_{(VA\ span=1.12)} = 3.26$) , while for morphologically simple items a larger VA span was related to larger lexicality effects (e.g., $t_{(\text{VA span}=-0.88)} = 3.96$, $t_{(\text{VA span}=-0.48)} = 5.60$, $t_{(\text{VA span}=-0.08)} = 7.10$, $t_{(\text{VA span}=0.32)} = 7.60$, $t_{(\text{VA span}=0.72)} = 7.13$, $t_{(\text{VA span}=1.12)} = 6.34$, see figure 2).

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

<Insert Figure 2 here>

## Discussion

The present study aimed to test whether young readers of Basque would: a) show a naming benefit when naming words and pseudowords including sub-lexical morphemes, and b) demonstrate differences in the influence of VA span skills on naming depending on the presence of sub-lexical morphemes in the stimuli. The main results on these two points could be summarised as follows: a) a significant morphological benefit was observed on the naming accuracy of words in early readers, and of pseudowords in advanced readers, b) for children in 2$^{nd}$ grade, a larger VA span was related to more accurate naming regardless of morphological structure, whereas in 4$^{th}$ grade a larger VA span was related to lexicality effects (differences in naming performance on words as compared to pseudowords) for the morphologically simple items.

**Morphological benefit in naming.**

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

We argue that the presence of a morphological benefit in pseudoword naming in 4$^{th}$ but not 2$^{nd}$ grade children is related to the morphological composition of the complex pseudowords, which were made up of a single real morpheme (stem or suffix) and a pseudomorpheme, and reflects 4$^{th}$ grade readers´ increased ability to process larger orthographic units even during fine grain phonological decoding. More specifically, at the early stages of reading acquisition, fine grain processing mainly relies on grapheme to phoneme mapping rather than processing larger orthographic units such as morphemes (Ehri, 2005; Frith, 1985; Share & Stanovich, 1995). Thus, it may have been more difficult for children in the 2$^{nd}$ grade to identify morphemes embedded in the pseudowords. Certainly, constructing morphologically complex pseudowords using two real morphemes (as was the case in previous studies: e.g., Burani et al., 2002) could increase the possibility of observing a benefit in early readers. This has been shown in a study in which pseudowords with a real stem and real suffix (in a non-existing combination) were read more accurately and faster than pseudowords with a pseudo stem and a real suffix, that were in turn read more accurately than pseudowords with a pseudo stem and a pseudo suffix (Colé et al., 2012).

Importantly, although the benefit was clearer in the pseudowords with a real stem and a real suffix, a benefit was also observed in the pseudo stem and real suffix condition. Similarly Traficante et al., (2011) showed that naming accuracy was higher for pseudowords including *either* a real root or a real suffix, although onset of pronunciation was earlier only for those including a real root. The results of both these studies (Colé et al., 2012; Traficante et al., 2011) suggest that any regularity that has been internalized (either root or suffix) can exert facilitation on pseudoword reading, because of early activation of the root. Probably because of its earlier position in the word, the root has a special impact on naming onset, and this index could magnify root facilitative effects. In the present study, whole word reading times were examined in order to capture any possible facilitation derived from any morpheme, regardless of whether it was positioned and thus identified earlier or later within the pseudoword. This procedure could in fact explain the absence of any differences between the two types of pseudowords that composed the morphologically complex pseudoword condition (stem + pseudosuffix, pseudostem + suffix). Alternatively, it could be the case that whole word reading times are not sensitive enough to study these differences, since they may also reflect additional sources of variability such as articulation speed. There is however good source of evidence reporting lexicality, frequency and morphological effects in children using this measure, suggesting it is a sensitive measure for such effects (Carlisle & Katz, 2006; Lallier et al., 2016).

With respect to word naming, the presence of a morphological benefit in accuracy for children in the 2$^{nd}$ but not the 4$^{th}$ grade suggests that whereas the presence of morphemes no longer affected word naming for skilled readers who probably identified most words as a whole (Angelelli et al., 2014; Marcolini et al., 2011), it may have boosted coarse grain processing in early readers who are still developing grapheme-to-phoneme reading skills, possibly through the activation of the whole word based on the stem (Beyersmann, Grainger, Casalis, & Ziegler, 2015; Hasenäcker, Beyersmann, & Schroeder, 2016). We further investigated this interpretation by comparing the proportion of lexicalisation errors compared to other types of errors in both age groups[3]. A higher proportion of lexicalisation errors is suggested to reflect greater reliance on coarse grain processing (Ellis et al., 2004). Although children in the two grades had similar odds of making lexicalisation errors overall ($p$ = .64), children in the 2nd grade had significantly higher odds of making lexicalisation errors when naming morphologically complex as compared to simple words (5.5 times higher odds, 95% CI [1.31, 27.62], $p$ = .03875), while this was not the case for children in the 4th grade ($p$ = .91). This supports the interpretation that coarse grain processing was boosted by the presence of morphemes for early readers when reading real lexical items, but not when reading pseudowords.

Our restrictive stimulus selection grounded on the manipulation of both stem and word frequency across conditions may have also limited the effects of morphological complexity in word naming speed. Note that previous studies have demonstrated that effects of stem frequency are observed in low frequency morphologically complex words (Deacon, Whalen, & Kirby, 2011; also see Deacon & Francis, 2017). We included both high and low frequency morphologically complex words that in turn included both high and low frequency stems. However, this manipulation did not lead to any interaction between these factors or between these factors and the other variables of interest[4]. All children showed frequency effects in all word conditions (see also Marcolini et al., 2011). This provides support to previous evidence suggesting that reading time is mainly driven by whole word frequencies (Carlisle & Katz, 2006; Mann & Singson, 2003), although this does rule out the presence of morphological effects, such as the influence of stem frequency on reading . It could be the case that the inclusion of high frequency morphologically complex words in our study may have decreased the bias towards processing their morphological constituents and even more so in the case of items with low frequency stems, leading to morphological effects in accuracy but not in reading times. The absence of an interaction between stem and whole word frequency (also reported in a previous adult study: Baayen, Wurm, & Aycock, 2007) could be related either to the blocked design, or to the nature of the task.

Another limitation of our design that may have influenced our results was the use of fixed trial order for the presentation of our stimuli. Nevertheless, if trial order had a large influence on performance (particularly expected on naming speed) the presentation of the complex stimuli before the simple stimuli should have increased the chance of seeing a morphological benefit, which in fact was absent in naming times.

Nonetheless, overall, this set of results suggests that sub-lexical units become accessible earlier than whole word units along the course of reading development, and may therefore serve as an intermediate grain (Burani et al., 2002; Hasenäcker, Schröter, & Schroeder, 2017) that facilitates the build-up of efficient and automatic lexical reading.

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

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

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

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

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

In line with this interpretation, a potential variable that could explain lexicality effects in 4$^{th}$ grade was N size.  Concretely, this factor might be the reason for the larger lexicality effects in simple low N words in 4$^{th}$ grade. As noted in the methods section, morphologically simple pseudowords were the only set of stimuli that had fewer orthographic neighbours. This could explain why children with a large VA span show facilitative effects in simple low N words, and not in simple high N words (which might exert inhibitory effects).

There was a larger difference in orthographic neighbourhood size between the morphologically simple words and morphologically simple pseudowords than between the morphologically complex words and the morphologically complex pseudowords. If, as stated in the introduction, a larger orthographic neighbourhood biases towards coarse grain processing and thus to greater reliance on VA span skills (Ans, Carbonnel, & Valdois, 1998), this fact could also explain the absence of a modulation of lexicality effects in the morphologically complex stimuli by VA span skills. More specifically, VA span skills may have been similarly involved in processing morphologically complex words and morphologically complex pseudowords if both types of item had similar numbers of orthographic neighbours and thus biased readers towards lexical, coarse grain processing. We consider this unlikely given our blocked design. In such a design, the readers are more likely to notice they are reading a list of pseudowords (even if they are morphologically complex). When reading a list of pseudowords it is more appropriate to consider that by default the VA span will focus on sub-lexical processing (Ans et al., 1998), and thus be less susceptible to orthographic neighbourhood effects. Still, we decided to test whether adding orthographic neighbours as a control variable in the fixed effects of all our models would change the observed effects. The pattern of significance remained the same suggesting that differences in orthographic neighbourhood size did not drive our results.

Our findings also support a relation between VA span skills and naming in Basque. Nevertheless, the previously reported correlation between better VA span skills and faster naming (Germano et al., 2014; van den Boer, de Jong, & Haentjens-van Meeteren, 2013; van den Boer et al., 2014, 2015) was absent. Two language-related factors may decrease the role of VA span skills in Basque: the shallow orthography and the rich agglutinative morphology. While the VA span - reading fluency correlation has been reported in other shallow orthographies (Spanish: Lallier, Valdois, Lassus-Sangosse, Prado, & Kandel, 2014; Onochie-

Quintanilla et al., 2017, Dutch: van den Boer et al., 2013, 2014, 2015), there is also evidence that it may be weaker than in deeper orthographies. For example, Onochie-Quintanilla et al. (2017) found that VA span significantly predicted reading fluency only for low frequency, long words, while Awadh et al. (2016) reported that VA span skills correlated with adult reading fluency in readers of French (a deeper orthography), but not Spanish. In the case of Basque, its rich and productive derivational morphology is not the only factor that may affect the VA span contribution to reading. In fact, the agglutinative nature of this language generates polymorphemic words composed of easily identifiable high frequency morphemes such as articles, postpositions, and inflections. As a result, reading in Basque may require higher sensitivity to morphological and syntactic structures at the word level and thus involve different visual attentional strategies. Cross-linguistic studies on similarly shallow orthographies that differ in relation to their morphology, such as Spanish and Basque, could shed light on this issue.

In conclusion, our results support that both early and advanced readers of Basque are sensitive to the presence of sub-lexical morphemes, primarily when coarse grain processing fails. Moreover, the role of VA span skills in naming is modulated by the presence of sub-lexical morphemes in advanced but not early readers. Further research on the influence of visuo-attentional demands in reading development should explore both the influence of orthographic consistency and morphological complexity in order to understand the obstacles faced by poor readers of different languages (also see: Diamanti, Goulandris, Campbell, & Protopapas, 2018).

## Acknowledgments

We would like to thank all the children, their families and schools for their participation. We would also like to thank the three reviewers for their very helpful comments on the manuscript. This paper will also be published as part of a dissertation.

## Declaration of conflicting interests

The authors declare that there is no conflict of interest.

## Funding

The authors acknowledge financial support from the Basque Government (PRE_2015_2_0049 to A. A.), the European Research Council (ERC-2011-ADG-295362 to M.C.), the Spanish Ministry of Economy and Competitiveness (PSI20153653383P to M.L., PSI20153673533R to M. C, and SEV-2015-490 awarded to the BCBL through the “Severo Ochoa Program for Centers/Units of Excellence in R&D”).

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Footnotes

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

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

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

[4] This refers to the analysis of naming speed measures. Naming accuracy could not be analysed for words only due to ceiling effects.

Table 1

*Descriptive statistics on age and performance on control tasks in both grades*

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

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

Table 2

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

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

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

Figure Captions

**Fig 1** Grade by lexicality by morphological complexity interaction on naming accuracy. Lines represent model predictions for means by condition and upper and lower 95% confidence intervals. Points represent by subject and condition averaged original scores.

**Fig 2** Influence of VA span skills on lexicality effects on naming times in $4^{th}$ grade. Points represent by subject lexicality effects (by subject averaged pseudoword - word log naming times), lines reflect lexicality effects as calculated based on model predictions on naming times averaged by condition and VA span scores (ranging from -1 to 1.2 with a step of 0.01). A positive lexicality effect indicates words were named more rapidly than pseudowords.

# Appendix A

Table A1

*Stimuli used in the naming task on morphological processing*

| Complex words | Word frequency [a] | | Stem frequency [a] | | Mean bigram token frequency | Orth. neighb.[b] | Simple words | Word frequency [a] | | Mean bigram token frequency | Orth. neighb. [b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Category | Zipf freq. | Category | Zipf freq. | | | | Category | Zipf freq. | | |
| euskaldun | high | 4.94 | high | 5.52 | 131 | 0 | ezaugarri | high | 4.93 | 250 | 1 |
| elkarte | high | 4.96 | high | 5.22 | 371 | 1 | alargun | high | 4.13 | 140 | 0 |
| orokor | high | 4.44 | high | 5.46 | 113 | 0 | aurpegi | high | 4.99 | 258 | 0 |
| aldizkari | high | 4.50 | high | 5.83 | 169 | 0 | harreman | high | 5.05 | 591 | 1 |
| emaitza | high | 5.18 | high | 6.31 | 221 | 3 | borroka | high | 5.21 | 435 | 0 |
| langile | high | 5.22 | high | 6.02 | 195 | 0 | ondorio | high | 5.12 | 363 | 1 |
| ondorengo | high | 4.80 | high | 5.95 | 168 | 0 | istripu | high | 4.62 | 147 | 0 |
| ariketa | high | 4.47 | high | 6.36 | 233 | 1 | zuhaitz | high | 4.75 | 223 | 1 |
| jardun | high | 5.07 | high | 5.92 | 232 | 1 | tximeleta | high | 4.05 | 122 | 0 |
| egunkari | high | 4.79 | high | 6.10 | 201 | 0 | argazki | high | 5.03 | 215 | 0 |
| artzain | high | 4.59 | low | 3.67 | 287 | 1 | panpina | high | 4.01 | 216 | 0 |
| aldaketa | high | 5.32 | low | 4.30 | 269 | 0 | bilduma | high | 4.71 | 215 | 1 |
| azterketa | high | 5.04 | low | 4.03 | 220 | 0 | baserri | high | 4.40 | 385 | 1 |
| batzar | high | 4.69 | low | 2.85 | 579 | 1 | korapilo | high | 4.06 | 190 | 0 |
| aukera | high | 5.80 | low | 2.49 | 504 | 0 | adiskide | high | 4.92 | 170 | 0 |
| ordezkari | high | 4.99 | low | 4.12 | 160 | 0 | arrakasta | high | 5.00 | 187 | 0 |
| margolari | high | 4.06 | low | 4.11 | 194 | 0 | eskaini | high | 5.32 | 230 | 0 |
| irabazle | high | 4.38 | low | 4.21 | 203 | 0 | erantzun | high | 5.78 | 566 | 0 |
| lorategi | high | 4.10 | low | 3.03 | 342 | 0 | otoitz | high | 4.83 | 129 | 0 |
| iraultza | high | 4.70 | low | 2.68 | 261 | 0 | zerrenda | high | 5.09 | 442 | 1 |
| behitegi | low | 2.41 | high | 4.58 | 336 | 0 | ukuilu | low | 3.43 | 35 | 3 |
| osagile | low | 2.60 | high | 5.08 | 118 | 0 | legamia | low | 3.13 | 142 | 0 |
| elurte | low | 3.55 | high | 4.58 | 139 | 1 | berakatz | low | 2.54 | 448 | 0 |
| saridun | low | 3.25 | high | 4.93 | 312 | 0 | lursail | low | 3.12 | 211 | 0 |
| bereizle | low | 2.76 | high | 4.13 | 340 | 1 | guraize | low | 2.88 | 323 | 0 |
| berekoi | low | 3.15 | high | 6.67 | 529 | 1 | kriseilu | low | 3.48 | 43 | 0 |
| asmakari | low | 2.60 | high | 4.20 | 187 | 1 | olagarro | low | 3.15 | 194 | 0 |
| beldurti | low | 3.35 | high | 5.27 | 233 | 1 | goroldio | low | 3.29 | 174 | 0 |
| iheskor | low | 3.66 | high | 5.32 | 53 | 0 | izpiliku | low | 2.72 | 95 | 0 |
| zezenketa | low | 3.12 | high | 4.31 | 184 | 1 | txintxeta | low | 2.79 | 121 | 0 |
| iratxo | low | 3.29 | low | 3.98 | 306 | 0 | erdeinu | low | 3.09 | 183 | 2 |
| kexati | low | 3.03 | low | 3.94 | 175 | 1 | zingira | low | 3.44 | 439 | 1 |
| lohitsu | low | 3.00 | low | 3.80 | 145 | 0 | adaxka | low | 3.00 | 72 | 1 |
| nagikeria | low | 3.16 | low | 3.86 | 179 | 1 | torloju | low | 3.12 | 118 | 1 |
| erkaketa | low | 3.28 | low | 3.06 | 353 | 1 | zikoina | low | 3.19 | 174 | 0 |
| titidun | low | 1.95 | low | 3.89 | 143 | 0 | baraila | low | 2.82 | 562 | 1 |
| muntaketa | low | 3.41 | low | 4.00 | 230 | 0 | inauteri | low | 3.35 | 205 | 1 |
| segalari | low | 3.41 | low | 3.94 | 238 | 1 | zintzarri | low | 2.88 | 287 | 0 |
| dirdaitsu | low | 3.44 | low | 3.40 | 108 | 0 | gerruntze | low | 3.04 | 286 | 1 |
| eltzekari | low | 2.88 | low | 3.61 | 185 | 0 | mitxoleta | low | 3.26 | 153 | 1 |

*Continued on the next page*

| Complex pseudowords[c] | Stem frequency (Zipf) | Mean bigram token frequency | Orth. neighb. [b] | Simple pseudowords | Mean bigram token frequency | Orth. neighb. [b] |
|---|---|---|---|---|---|---|
| **euskal**tin | 5.52 | 119 | 0 | ataugatze | 114 | 0 |
| entan**te** | | 156 | 2 | alanken | 480 | 0 |
| **oro**tek | 5.46 | 581 | 1 | ainpesi | 107 | 0 |
| anbal**kari** | | 149 | 0 | harripen | 701 | 2 |
| igoi**tza** | | 173 | 1 | lerrota | 538 | 4 |
| mes**gile** | | 126 | 0 | osnorea | 255 | 0 |
| ontokil**go** | | 87 | 0 | inflixu | 32 | 0 |
| **ari**giro | 6.36 | 189 | 0 | muzaitz | 269 | 0 |
| **jar**ten | 5.92 | 1291 | 2 | tribizeta | 154 | 0 |
| **egun**gaku | 6.10 | 179 | 0 | alzizki | 161 | 1 |
| ent**zain** | | 214 | 1 | zarkina | 407 | 0 |
| **alda**miro | 4.30 | 109 | 0 | bardoma | 364 | 0 |
| exkar**keta** | | 213 | 1 | bafeklo | 163 | 0 |
| **batz**on | 2.85 | 540 | 2 | dirafino | 152 | 0 |
| **au**tika | 2.49 | 222 | 0 | amaktide | 146 | 0 |
| **ordez**taku | 4.12 | 166 | 0 | arratenra | 230 | 0 |
| hesfo**lari** | | 149 | 0 | eldeuni | 110 | 0 |
| ilahos**le** | | 30 | 0 | eroltxun | 175 | 0 |
| biti**tegi** | | 286 | 1 | asoitz | 125 | 0 |
| **iraul**txe | 2.68 | 192 | 0 | zerrurga | 329 | 0 |
| **behi**lezu | 4.58 | 259 | 0 | uduizi | 55 | 0 |
| **osa**zigu | 5.08 | 94 | 0 | sahadia | 224 | 0 |
| ekis**te** | | 77 | 0 | biraritz | 338 | 0 |
| **sari**zar | 4.93 | 309 | 0 | gurlail | 292 | 0 |
| **bereiz**di | 4.13 | 341 | 1 | kurauzi | 218 | 0 |
| bili**koi** | | 174 | 0 | frinaulu | 105 | 0 |
| imne**kari** | | 171 | 0 | oxibarra | 238 | 1 |
| bezkor**ti** | | 233 | 0 | gorepzio | 192 | 0 |
| **ihes**tal | 5.32 | 204 | 0 | ispareku | 234 | 0 |
| demal**keta** | | 140 | 0 | txartzeta | 226 | 0 |
| **ira**rra | 3.98 | 507 | 7 | erdeuli | 163 | 0 |
| mima**ti** | | 201 | 1 | zirbika | 244 | 1 |
| **lohi**klo | 3.80 | 100 | 0 | aziska | 75 | 0 |
| zita**keria** | | 241 | 0 | targoxu | 231 | 0 |
| **erka**liro | 3.06 | 223 | 0 | likeila | 165 | 0 |
| nebi**dun** | | 72 | 0 | bagoina | 304 | 0 |
| horda**keta** | | 209 | 1 | otaurere | 113 | 0 |
| **sega**zare | 3.94 | 154 | 0 | zaltsarri | 242 | 0 |
| dunkai**tsu** | | 95 | 0 | zerrontzi | 271 | 0 |
| **eltze**rake | 3.61 | 229 | 0 | botxuseta | 88 | 0 |

[a] items are marked as high or low frequency depending on whether Zipf frequency was above or below 4 respectively (Van Heuven, Mandera, Keuleers, & Brysbaert, 2014). In the case of stem frequency the cut-off between low and high was slightly higher. Measures used only for words were taken from the EHME database (Acha et al., 2014). Measures that were needed for both words and pseudowords were taken from E-HITZ (Perea et al., 2006). [b] Orthographic neighbours. [c] the real morpheme is presented in boldface.

Table A2

*Descriptive statistics of the variables used to match the naming task stimuli on our main conditions of interest*

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

[a] Wilcoxon signed rank tests were used for the comparisons.

Table A3

*Descriptive statistics on the word and stem frequencies of the word subsets that we investigated in our additional analyses*

| Word subsets | Word frequency | Stem frequency | Length | | Average bigram token frequency | | Word frequency (Zipf) | | Stem frequency (Zipf) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean *(SD)* | Range | Mean *(SD)* | Range | Mean *(SD)* | Range | Mean *(SD)* | Range |
| Simple | High | | 7.5 *(0.83)* | 6 - 9 | 274 *(141)* | 122 - 591 | 4.8 *(0.47)* | 4.01 – 5.78 | | |
| | Low | | 7.6 *(0.94)* | 6 - 9 | 213 *(141)* | 35 – 562 | 3.09 *(0.25)* | 2.54 - 3.48 | | |
| Complex | High | High | 7.5 *(1.18)* | 6 - 9 | 203 *(71)* | 113 – 371 | 4.84 *(0.29)* | 4.44 – 5.22 | 5.87 *(0.37)* | 5.22 - 6.36 |
| | | Low | 7.8 *(1.14)* | 6 - 9 | 302 *(138)* | 160 – 579 | 4.77 *(0.54)* | 4.06 - 5.80 | 3.55 *(0.71)* | 2.49 – 4.30 |
| | Low | High | 7.5 *(0.85)* | 6 - 9 | 243 *(139)* | 53 – 529 | 3.04 *(0.43)* | 2.41 – 3.66 | 4.91 *(0.75)* | 4.13 - 6.67 |
| | | Low | 7.8 *(1.23)* | 6 - 9 | 206 *(77)* | 108 – 353 | 3.08 *(0.44)* | 1.95- 3.44 | 3.75 *(0.31)* | 3.06 – 4.00 |

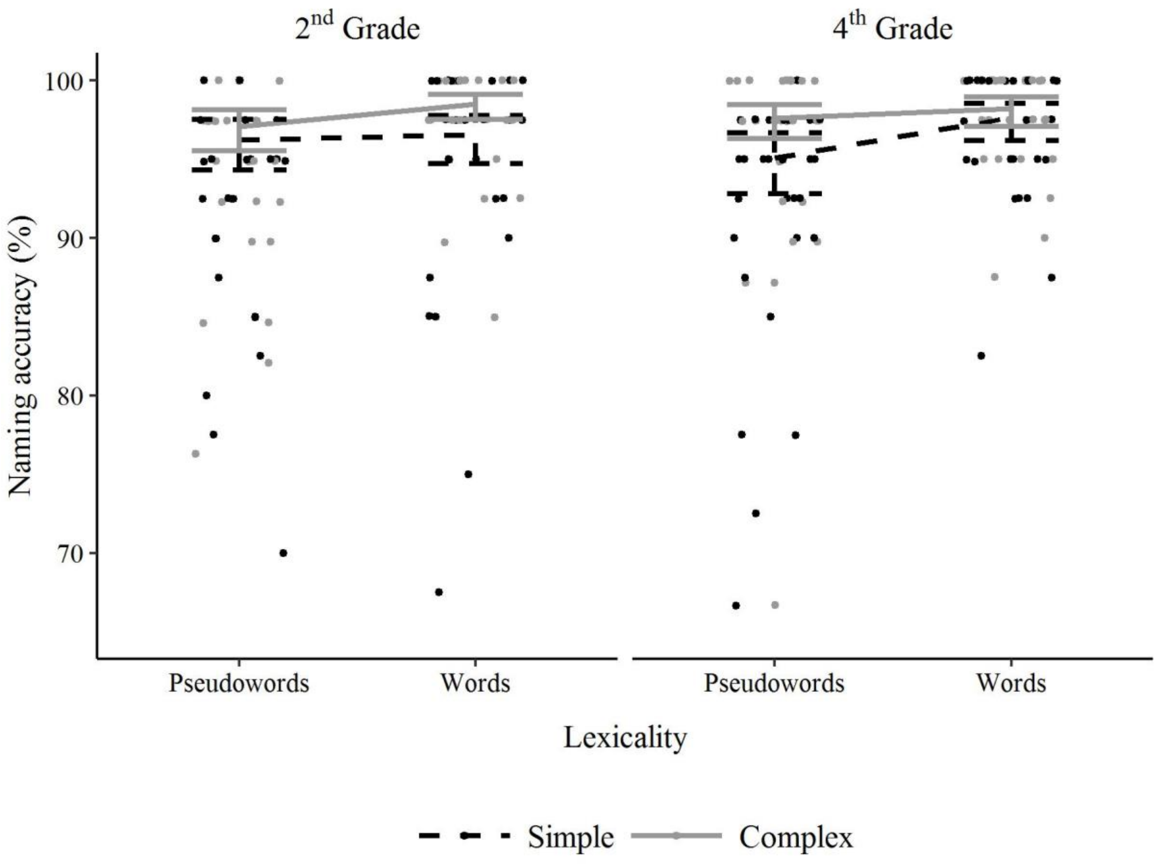
2nd Grade
4th Grade
Naming accuracy (%)
100
90
80
70
Pseudowords
Words
Pseudowords
Words
Lexicality
Simple
Complex

**Figure 1**

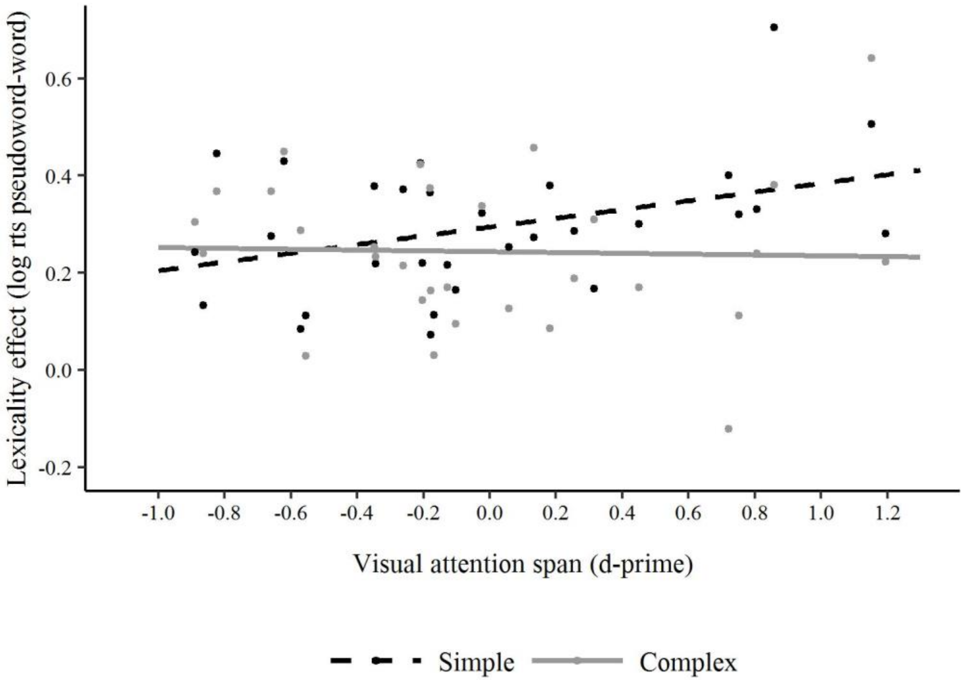
Lexicality effect (log rts pseudoword-word)
0.6
0.4
0.2
0.0
-0.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Visual attention span (d-prime)
Simple
Complex

**Figure 2**