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**Orthographic Learning and Transfer of Complex Words: Insights from Eye-Tracking  
During Reading and Learning Tasks**

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To download Supplementary Material files (data, statistical models and appendix), please use this link: [https://osf.io/jpbnz/?view\\_only=289450b9cf1f40efad6aec751b6b0a20](https://osf.io/jpbnz/?view_only=289450b9cf1f40efad6aec751b6b0a20)

### **Abstract**

**Background:** Efficient word identification is directly tied to strong mental representations of words, which include spellings, meanings, and pronunciations. Orthographic learning is the process by which spellings for individual words are acquired.

**Methods:** In the present study, we combined the classic self-teaching paradigm with eye-tracking to detail the process by which complex pseudowords are learned. With this methodology, we explored the visual processing and learning of complex pseudowords, as well as the transfer of that learning. We explore visual processing across exposures during the initial reading task and then measure learning and transfer in orthographic choice and spelling tasks.

**Results:** Online eye movement monitoring during the repeated reading of complex pseudowords revealed that visual processing varied across exposures with key differences based on word type. Further, data from both dictation and eye movements recorded during the orthographic choice task suggested stronger learning of morphologically than orthographically complex pseudowords after four encounters. Finally, results suggested that learning transfer occurred, with similar levels of accurate recognition of new pseudowords that were morphologically or orthographically related to pseudowords learned during the reading phase than of new pseudowords never read.

**Conclusions:** The present study provides new insights into theory and methodological discussions of orthographic learning.

**Keywords:** orthographic learning, morphology, transfer of learning.

## **Implications for Practice**

### **What Is Already Known About This Topic**

- Children and adults learn new words through their reading, an effect robustly demonstrated through the self-teaching paradigm.
- Recent research shows that children transfer their learning of new words to that of other words, with little consensus as to how this happens.

### **What This Paper Adds**

- In this study, we evaluate in detail the process of this learning by combining behavioral assessed with the classic self-teaching paradigm with eye movement monitoring. Eye movement monitoring during repeated exposures to pseudowords revealed differences in eye movements between morphologically and orthographically complex pseudowords suggesting differences in visual processing during learning itself.
- Evidence of stronger learning for the spellings of morphologically complex pseudowords emerged from both behavioral and eye movement data.
- We found that learning transferred to new pseudowords, and did so to a similar extent whether they were morphologically or orthographically related to learned pseudowords.

### **Implications For Theory, Policy Or Practice**

- Methodologically, we demonstrate the value of including eye-tracking to evaluate orthographic learning in a self-teaching paradigm, both during reading itself and during later processing. Our findings confirm the effectiveness of this technique to investigate orthographic learning and learning transfer.
- The self-teaching hypothesis is the most popular theoretical model of orthographic learning, predictions of which have been questioned in recent studies. Through this study, we provide fresh empirical tests of the cognitive mechanisms in this model, specifying current models of reading.

Efficient word identification is directly tied to strong mental representations of words, which include spellings, meanings and pronunciations (Ehri, 2005; Perfetti, 2007). Orthographic learning is the process by which these representations for individual words are acquired (Share, 2008). The Self-Teaching Hypothesis suggests that new words are learned through phonological recoding, a built-in teaching mechanism, enabling the learning of individual words with exposure to each word directly tied to its learning (Share, 1995). With accumulated reading experience, the phonological recoding process is predicted to include morphemic constraints (Share, 1995; 2008), leading to the prediction that new words will be differentially processed as they are read based on morphological structure. In the present study, we use the self-teaching paradigm (Share, 1999) to test the potential effects of morphological structure on the visual processing and learning of new words. We also explore the potential transfer of this learning, testing the strong prediction that learning of each word is tied to exposure to that precise word (Share, 1995).

Our first question lies in whether there are effects of morphological structure in the visual processing of new words across exposures – effectively during learning. Standard self-teaching paradigms involve participants reading four instances of a new word in a story, and they typically assess the outcome of this processing with measures of learning such as an orthographic choice task (Share, 1999; see Tucker et al., 2016 for a recent example). Several studies have demonstrated that learning is more effective with increasing exposures (e.g., Share, 1999), including in studies combining both behavioral measures with eye-tracking. For instance, Joseph et al. (2014) found that participants fixated on and viewed new words for less time with more exposures and Li et al., (2019) reported decreases in the number of fixations (as well as regressions back to) across encounters (see also Ginestet et al., 2020). It seems that processing might become increasingly efficient across exposures. In the present study, we build on this work

to explore the novel question of whether the visual processing of morphologically complex and orthographically complex (yet morphologically simple) pseudowords differs across exposures to them in story reading.

We use eye-tracking to explore this question. Applying eye-tracking encouraged us to study three-morpheme pseudowords because it enabled us to explore visual processing in finer detail within words, while also considering processing of greater morphological complexity than in prior studies. Eye-tracking has been used recently in other studies of orthographic learning of novel words, albeit addressing other factors (e.g., Joseph et al., 2014; Joseph & Nation, 2018; Li et al., 2019). Available research applying eye-tracking to the study of morphological complexity tends to use known words. In a study examining English speaking adults' reading of words embedded in short sentences, Inhoff et al. (1996) found that gaze durations and first fixation durations were longer on compound words than on suffixed and monomorphemic words, which did not significantly differ with each other. Similarly, Yan et al. (2014; see also Hyönä et al., 2018) found that gaze durations and first fixation durations increased with morphological complexity during the reading of Uighur words presented in sentences. Further, initial landing positions were closer to the beginning of morphologically complex than simple words (Yan et al., 2014). Together these studies of known words, suggest that morphological complexity sometimes makes visual processing of words more difficult, requiring longer fixation durations. Turning to one of the few prior studies of pseudowords, Breadmore and Carroll (2018) investigated the visual processing of pseudowords (i.e., existing verbs containing an error) read in sentences by native speakers. English-speaking adults had longer reading times for morphologically complex pseudowords (over-regularizations) than for the correct verb forms. More interestingly, they reported shorter total fixation duration for morphologically complex

pseudowords than for monomorphemic pseudohomophones suggesting that morphological structure might aid visual processing of pseudowords. Regardless of the direction of effects, these studies indicate the insight looking at eye movements can provide into the influence of morphological structure on processing.

Our second research question is whether there might be stronger learning for morphologically than for orthographically complex pseudowords following on the reading experience. To date, there are conflicting findings from diverging methods. In the single available study on the learning of new words, Tucker and colleagues (2016) studied learning of orthographically and morphologically complex pseudowords (e.g., *feaple* and *feaper*, respectively) within a self-teaching paradigm. In this between-subjects manipulation, Tucker et al. (2016) found that children in Grades 3 and 5 learned the spellings of morphologically and orthographically complex pseudowords to a similar extent, based on parity in levels of success on an orthographic choice task.

In contrast, two studies of similarly aged French-speaking children found that the presence of morphologically related words along with a base form enabled stronger learning of the base form in contrast to control conditions that include multiple presentations without clear morphological relations (Pacton et al., 2018; see also Pacton et al., 2013). Pacton et al. (2018) suggested that the presence of morphological information during the process of orthographic learning improved the outcome of this learning. That said, this study contrasted the type of words presented in the learning context (e.g., the kinds of words in the stories), rather than the morphological structure of the words that the children were tested on. Nevertheless, these results align with studies of known words showing that children learn morphologically complex words better than those without such a structure, both in terms of greater accuracy and speed in their

reading and spelling (e.g., *turning* versus *turnip*; Deacon & Dhooge, 2010; Deacon et al., 2011). Given the conflicting findings to date on the effect of morphological structure on the learning of words, we explore it here by examining the impact of pseudoword morphological structure on performance during spelling and orthographic choice tasks.

Our third and final question lies in whether readers transfer their learning and whether this is influenced by morphological structure. Tucker et al (2016) suggested that learning of one pseudoword transfers to other newly encountered pseudowords, contrasting with Share's (1995) initial predictions of item-by-item learning. Tucker et al., (2016) found that English-speaking children were equally likely to transfer their learning of pseudowords read in short stories (e.g., *feap*) to other pseudowords that were morphologically related, as to those that simply shared the same orthographic structure (e.g., *feaper* and *feaple*). These effects emerged in an orthographic choice task and suggest that children transfer their prior learning to that of new words, with no additional benefit of morphological relatedness. Given that this question has only been examined in a single study to date, it seems important to continue exploration, especially with potentially more sensitive metrics.

### **The Current Study**

We investigated the effects of morphological structure on the processing and learning of new words, as well as the transfer of that learning. We used a self-teaching task (e.g., Share, 1999), in which participants read short stories that included pseudowords while their eye movements were recorded. As suggested by Bowey and Muller (2005) and de Jong and Share (2007), orthographic learning occurs similarly regardless of whether stories are read aloud or silently in a self-teaching paradigm. In the present study, we assumed an approach more typical of the self-teaching literature than of the eye movement method; specifically, tracking oral



reading of stories allowed us to track decoding of the novel words and to ensure engagement in the task. In a within-subjects manipulation, some of these were morphologically complex and others were morphologically simple. Eye-tracking during this task supplied real-time information about eye movements across exposures to the individual pseudowords as they were read (Bertram, 2011). We used this data to explore our first question regarding the processing of new words during reading. Subsequently, we used measures of learning to answer our second research question, in which target items were included in a dictation task and an orthographic choice task. To answer our final question of transfer, the orthographic choice task also included items assessing transfer of learning to new pseudowords (e.g., Tucker et al., 2016). We again measured eye movements in the orthographic choice task, in light of debate as to its sensitivity (Tucker et al., 2016; Wang et al., 2011).

Our first research question investigated whether there was differential visual processing during learning of morphologically versus orthographically complex pseudowords. Based on prior studies of eye movements with new words (e.g., Joseph et al., 2014; Joseph & Nation 2018; Li et al., 2019), we analysed classic eye-tracking measures, as they applied to the target pseudowords. These included the Number of Fixations (NF) during the first-pass, the Gaze Duration (GD) or the sum of the duration of fixations during the first-pass, and the Total Duration (TD) or the sum of all fixation durations (first-pass and later passes). We also explored fixation durations for both one (SFD for Single Fixation Duration) and two fixations (FTFD for First-of-Two Fixation Duration and STFD for Second-of-Two Fixation Duration) (Mousikou & Schroeder, 2019). Finally, we analyzed fixation positions to examine potential impacts of morphological structure on gaze position during the repeated reading of the pseudowords; like our analyses of fixation duration, these focused on gaze positions when one (SFP for Single

Fixation Position) or two fixations occurred (FTFP for First-of-Two Fixation Position and STFP for Second-of-Two Fixation Position). This wide capture maximises insight offered by eye movement measures into the real-time study of orthographic learning (Nation & Castles, 2017) including potential differences between early (SFD, FTFD, GD, SFP, FTFP) and later processing (NF, TD, STFD, STFP) (Bertram, 2011; see also Mousikou & Schroeder, 2019; Pagán & Nation, 2019). We expected an influence of morphological structure on early measures of visual processing leading to earlier initial landing positions (SFP and FTFP) and longer gaze durations (GD, SFD and FTFD) during the learning of morphologically versus orthographically complex words. An inhibitory effect of morphological complexity was also expected on later measures of eye movements (NF, TD, STFD and STFP), assuming that the presence of affixes might require more high-level cognitive processes to assess the meaning of the pseudowords (Hyönä et al., 2018). Finally, we expected to observe an easier visual processing of both types of pseudowords leading to a decrease of all fixation durations across exposures.

Our second research question examined whether there was stronger learning for morphologically than for orthographically complex pseudowords. No differences might emerge, as in Tucker et al. (2016). However, we expected that our within-subjects design might enable detection of stronger learning for morphologically than for orthographically complex pseudowords, as predicted by Pacton et al. (2013; 2018). This could emerge in higher levels of accuracy (and reduced visual processing time where measured) for morphologically versus orthographically complex pseudowords during dictation and orthographic choice tasks.

Our final research question was whether English speaking adults transfer learning of pseudowords to other pseudowords that are either morphologically or orthographically related. In line with earlier work, we predicted that orthographic learning would transfer to the processing

of pseudowords that were morphologically related to a similar extent as those that were orthographically related (Tucker et al., 2016). We expected similar levels of accuracy and looking time durations on transfer items in the orthographic choice task.

## Method

### Participants

A total of 56 university students with normal or corrected-to-normal vision took part in this study. We report data on 45 participants who met all criteria. Indeed, 3 out of the 56 participants did not complete the whole experiment, 3 were not native English speaker, 1 had cognitive difficulties, and 4 revealed word-level reading difficulties (i.e., word reading standard scores < 85). Of the remaining participants, 37 were females, 8 were males, and the average age was 20.8 years (SD = 2.5 years). Furthermore, the average TOWRE score was 106.2 (SD = 12.8) for Sight Word Efficiency and 103.7 (SD = 9.2) for Phonemic Decoding Efficiency.

### Apparatus

We used the Eyelink 1000 eye tracker (SR Research; Mississauga, Ontario, Canada). Eye movements were recorded from the right eye only at a sampling rate of 1000 Hz. Stimuli were presented on a 1920×1200 px resolution Mac computer screen (60 Hz refresh rate) with participants' eyes at a viewing distance of 81 cm. To keep this distance constant and prevent head movement, participants rested their foreheads on a head mount. In all tasks, stimuli were presented in black size 32 px Courier New font (which ensured equal distance between letters) against a light grey background, and the experiments were designed with Opensesame (Mathôt et al., 2012; v.3.1.2). The angular distance between letters was 0.37°.

## Materials

### *Item Creation*

Pseudowords with 8 or 9 letters were created to fit into two conditions.

The morphological condition included morphologically complex pseudowords with 3 morphemes: a real prefix (either *re-* or *mis-*), a non-word base, and a real suffix (*-er*) (e.g., *relerber* and *misdoaffer*). The orthographic condition had morphologically simple pseudowords of the same length; for these, the letters added before the non-word base (either *pe-* or *fis-*) and after (always *-le*) held no independent meaning in English (e.g., *pelerble* and *fisdoafle*). First letters (*re-* vs *pe-*, *mis-* vs *fis-* and final letters (*-er* vs *-le*) were chosen based on prior research with children (see Tucker et al., 2016). However, due to the increasing prevalence of morphologically complex words in English with age, the frequency of prefixes *re-* or *mis-* (respectively,  $f = 27,867$  and  $f = 3,495$  according to CELEX; Baayen et al., 1993) is higher than the frequency of initial string as *pe-* or *fis-* (respectively,  $f = 12,186$  and  $f = 609$  according to the CELEX) and the frequency of the suffix *-er* is higher than that of *-le* (respectively,  $f = 58,043$  and  $f = 35,756$  according to CELEX). All non-word bases and the complex pseudowords created from them were confirmed to be pseudowords using CELEX and MCWord (Medler & Binder, 2005). We also confirmed that all pseudowords did not have real word homonyms or orthographic neighbors (through dictionary.com). All pseudowords were constructed to be orthographically legal in English, with initial and final trigram frequencies that were greater than zero (according to CELEX) as well as whole word average bigram and trigram frequencies greater than zero (according to MCWord).

To summarize, we created four lists of 16 pseudowords, each with eight morphologically and eight orthographically complex pseudowords. The four lists were balanced for mean bigram ( $\beta = 0.02$ ,  $t = 0.25$ ,  $p = .803$ ) and trigram frequencies ( $\beta = 0.11$ ,  $t = 0.57$ ,  $p = .574$ ).

Participants read the 16 pseudowords in a within-subject design so that each participant learned items from both conditions. For example, one participant learned *releber* and *pejaitle* and another learned *pelerble* and *rejaieter*. We also created and counterbalanced homophones across conditions such that half of the participants learned an item as a target, and the other half learned its homophone twin (e.g., *relurber* and *releber*). Drawing on the above example, a third participant would then learn *relurber* and *pejaytle* and a fourth would learn *pelurble* and *rejayter*. Each homophone pair was pronounceable following English grapheme–phoneme correspondence rules (Rastle & Coltheart, 1999) and we also checked the regularity of the pronunciation of each homophone pair of bases (Wilson, 1988; Ziegler et al., 1997). A full list of items is provided as Supplementary Material<sup>1</sup> (see the “Appendix\_Stimuli\_lists” file).

### ***Orthographic Learning Task***

To address our first question, we examined visual processing during story reading. Participants read 16 stories out loud that included the pseudowords described above. Each story consisted of five sentences, the last four of which each included one exposure to the pseudoword (e.g., Mike has to go back outside during the storm and his hat gets wet. Mike decides to use the *relurber* to fix his problem. The handy *relurber* will make his hat dry again. Mike is glad the *relurber* can dry his hat. Mike makes sure to put the *relurber* away when he is finished). The first sentence was used to establish the semantic context of the story and all subsequent sentences were used to describe the use and function of the pseudoword. The sentences were presented one

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<sup>1</sup> Open access availability for Supplementary Material files:  
[https://osf.io/jpbnz/?view\\_only=289450b9cf1f40efad6aec751b6b0a20](https://osf.io/jpbnz/?view_only=289450b9cf1f40efad6aec751b6b0a20)

at a time, on a single horizontal line centered on the computer screen. Target pseudowords were never at the beginning or at the end of the sentence. Across the morphological and orthographic conditions, the sentences were matched on the number of words before the target so that the first word and 5 letters after the target word were the same (see Hyönä et al., 2018 for a similar approach). For the morphological condition, the meaning of the prefix and suffix in the pseudoword was consistent with its use in English (e.g., pseudowords beginning in *re-* were described as doing something again). During reading, the eye tracker recorded the participants' eye movements; we also recorded their pronunciation. No feedback was provided on reading accuracy.

### ***Dictation Task***

In the first outcome measure participants were asked to spell each of the pseudowords by typing them on a computer. Participants heard the pseudowords one at a time, spoken aloud through headphones. No feedback was provided during the task. Responses were considered correct only if the whole spelling was strictly identical to that presented during the reading task.

### ***Orthographic Choice Task***

The second outcome measure was designed to measure both the outcome of learning and its transfer (modeled on Tucker et al., 2016), addressing research questions 2 and 3. The task was completed on a computer so that we could monitor eye movements. Participants were shown four pseudowords arranged in a square around a fixation point on the screen (for a similar two by two display of items, see Mimeau et al., 2018). They were asked to choose the best spelling, based on what they had read in the stories. They were tested on the pseudowords they read as well as transfer items for a total of 48 trials.

Within the orthographic choice task, the participants chose from four options: the learned or transfer pseudoword, a homophone of that pseudoword, a distractor and a homophone of the distractor (e.g., *relurber*, *relerber*, *relurger*, *relerger*). The first distractor was created by replacing a consonant in the pseudoword base with another consonant (*relurger* for *relurber*). The second distractor is the homophone of the first distractor (*relerger* for *relurger*). No feedback was provided during this task.

Transfer items were either morphologically or orthographically related to the learned pseudowords. All transfer items shared the same non-word base as the pseudowords learned; only the letters at the beginning were changed and the letters at the end were removed. For the morphologically related pseudowords, the suffix was replaced with another real word suffix; the letters *re-* and *mis-* were changed to *mis-* and *re-*, respectively. Similarly, for the orthographically related pseudowords, the letters *pe-* and *fis-* were changed to *fis-* and *pe-*, respectively. For each pseudoword, the two last letters were removed. As an example, for the target pseudoword *relurber* we used *mislurb* to test morphological transfer and *fislurb* to test orthographic transfer.

### ***Test Of Word Reading Efficiency (TOWRE-2)***

Lastly, participants completed the TOWRE-2 (Torgesen et al., 2012) to assess reading level. In each subtest, participants were asked to read as many real words or pseudowords as they could in 45 seconds.

### **Procedure**

All testing was completed during a single session in a quiet testing room. Participants completed tasks in the order above. Prior to each eye-tracking task, we conducted a 5-point calibration. During the orthographic learning task, stories were presented in a random order and

preceded by a manual drift correction dot centered on the screen. To avoid any anarchical initial gaze position, each sentence was preceded by a fixation cross indicating the position of the first letter of the sentence. The participant had to keep their eyes on this cross between 150 to 250 ms to display the whole sentence, allowing recalibration if necessary.

In the orthographic choice task, each trial was preceded by a fixation dot centered on the screen serving as a drift correction. After manual validation, the four stimuli appeared. Position of the target items was counterbalanced, with target pseudowords randomly appearing 12 times in each corner of the square.

For each of these tasks as well as for the dictation task, participants pressed the space bar to move onto the next trial so that there was no time limit imposed. In each task, test trials were preceded by at least 2 practice trials to ensure understanding of the instructions.

## Results

### Statistical Models

Raw data from all tasks were analyzed by means of generalized linear mixed effects models (glmer function; R Core Team, 2018; RStudio version 1.0.143). In all statistical models, participants and items were introduced as random factors and initial bigram (for items beginning by *re-* or *pe-*) or trigram (for items beginning by *mis-* or *fis-*) log-frequency was included as covariate. As an exception, word length was also considered as covariate for the analysis of the nature effect (new vs. old items) on gaze duration from the orthographic choice task. This was done assuming a potential word length effect on visual processing due to the large range of word lengths (from 6 to 9 letters) of items compared through this model.



We used the Gamma family and the identity link for reaction time (RT) data (including temporal measures from eye-tracking data), the Poisson family and the identity link for the analysis of the number of fixations, the Gaussian family and the identity link for the analysis of fixation positions, and the Binomial family and the logit link for binomial variables such as accuracy. In all models, contrasts were specified as 0.5/-0.5 or 1.5/0.5/-0.5/-1.5 respectively for independent variables which have 2 or 4 modalities.

Models from the orthographic learning task included the within-subjects variables of number of exposures (1, 2, 3, 4) and item type (morphologically vs. orthographically complex) as well as their interaction as fixed factors. Models from the dictation task included item type (morphologically vs. orthographically complex) as a fixed factor. In models related to the orthographic choice task, three independent fixed factors were considered in 3 different models: the within-subjects variable of item type (morphologically vs. orthographically complex), transfer type (morphologically vs. orthographically related) and nature (new vs. old items).

Finally, a maximal random effects structure was first specified for all models including all subject and item random intercepts and random slopes (Barr et al., 2013). Following Barr et al. (2013) recommendations and in the case of a model failing to converge, we removed first correlations between random factors, then random interactions, and lastly random slopes associated with smaller variance, until the model converged. Full model details and results are provided as Supplementary Material<sup>2</sup> (for a quick access to statistical models, see the .html file in “Statistical\_files” folder).

## Eye-Tracking Data Cleaning

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<sup>2</sup> Open access availability for Supplementary Material files:  
[https://osf.io/jpbnz/?view\\_only=289450b9cf1f40efad6aec751b6b0a20](https://osf.io/jpbnz/?view_only=289450b9cf1f40efad6aec751b6b0a20)

Raw data were parsed using the Eyelink cognitive configuration. We used a custom-designed software developed from the technical computing system Mathematica (Wolfram Research Inc., Champaign, Illinois, United States; v.11.0) to select the relevant fixations for subsequent analyses. For both the orthographic learning and orthographic choice tasks, only events that occurred within the area of interest (i.e., area around the target word) were analyzed<sup>3</sup>.

For both the learning and orthographic choice tasks, we inspected and removed possible outliers<sup>4</sup>. First, trials containing more than one blink in the area of interest were removed. Then, trials with more than 6 fixations for the orthographic learning task and trials with more than 14 fixations for the orthographic choice task were considered as extreme outliers according to the interquartile range calculation  $Q_3 + 3 \times (Q_3 - Q_1)$ . Trials with total log-duration further than 2.5 standard-deviations from the mean were removed (range: 105 – 3,075 ms for the orthographic learning task; range: 163 – 4,125ms for the orthographic choice task). Fifth, we excluded trials with at least one fixation log-duration further than 2.5 standard-deviations from the mean (range: 67 – 792 ms for the orthographic learning task; range: 58 – 789 ms for the orthographic choice task). In total, we retained 90.9 % of trials (2,618 out of 2,880 trials<sup>5</sup>) from 45 participants and 89.2 % of trials (1,883 out of 2,112 trials) from 44 participants (due to technical issue, data from one participant were not recorded) for analysis.

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<sup>3</sup> These areas were defined as 0.57° to the left of the left boundary of the first letter, 0.57° to the right of the right boundary of the final letter and consistent vertical coordinate according to visual inspection carried out for each participant, for the orthographic learning task; 0.57° to the left of the left boundary of the first letter, 0.57° to the right of the right boundary of the final letter and more or less 3° from the center of the target word on the vertical axis, for the orthographic choice task.

<sup>4</sup> For the orthographic choice task, outliers were removed for the analysis of gaze duration but not for the analysis of accuracy.

<sup>5</sup> A complete breakdown of the number of trials considered as a function of item type and number of exposures is provided in Supplementary Material file “Complement for Eye-Tracking data”. See: [https://osf.io/jpbnz/?view\\_only=289450b9cf1f40efad6aec751b6b0a20](https://osf.io/jpbnz/?view_only=289450b9cf1f40efad6aec751b6b0a20).

## Data Analyses

### *Differences in the Processing During the Learning of Morphologically and Orthographically Complex Pseudowords*

To address our first research question, eye movements were recorded during the orthographic learning task itself allowing us to compare visual processing of morphologically and orthographically complex pseudowords during repeated reading. While most previous studies in the field focused on the duration of both single fixation and first-of-multiple fixations (e.g., Joseph et al., 2014), we restricted analyses of fixation duration and position to trials in which the target pseudoword was fixated upon once or twice (Mousikou & Schroeder, 2019). This proposal is doubly motivated; eye movement data from the orthographic learning task revealed that 58 % of trials required one (24.6 %) or two (33.3 %) fixations, and analysis of first-of-multiple fixations duration<sup>6</sup> revealed similar effects to those obtained analysing the first-of-two fixation duration. Thus, the analysis of two-fixation trials allowed an in-depth analysis of both the first and second fixation duration, while capturing patterns similar across more fixations, thereby allowing us to provide insights related to our first research question.

The number of exposures and item type did have an effect on visual processing times – and consequently, the number of fixations –for the pseudowords (see Figure 1). Namely, NF, GD, TD, FTFD and STFD significantly decreased across exposures (respectively,  $\beta = 0.41$ ,  $z = 15.05$ ;  $\beta = 124.73$ ,  $t = 26.90$ ;  $\beta = 197.45$ ,  $t = 43.82$ ;  $\beta = 21.55$ ,  $t = 6.50$  and  $\beta = 12.11$ ,  $t = 3.68$ , all  $p_s < .001$ ), but SFD was not influenced by the number of exposures ( $\beta = 3.91$ ,  $t = 1.15$ ,  $p = .250$ ).

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<sup>6</sup> The analysis of first-of-multiple fixation duration showed a main effect of the number of exposures ( $\beta = 11.44$ ,  $t = 6.02$ ,  $p < .001$ ) but neither a main effect of item type ( $\beta = 4.85$ ,  $t = 0.78$ ,  $p = .438$ ) nor interaction effect ( $\beta = -0.88$ ,  $t = -0.24$ ,  $p = .810$ ).

There were significantly more fixations for orthographically complex than morphologically complex pseudowords ( $\beta = 0.17, z = 2.72, p = .006$ ). In line with this observation, there were also longer processing times for orthographically complex pseudowords over morphologically complex one (GD:  $\beta = 40.45, t = 4.52, p < .001$  and TD:  $\beta = 31.10, t = 4.14, p < .001$ ). In contrast, results did not show any significant effect of item type for SFD, FTFD and STFD (respectively,  $\beta = -4.03, t = -0.39, p = .697$ ;  $\beta = 7.47, t = 0.85, p = .393$ ;  $\beta = 12.43, t = 1.25, p = .210$ ) suggesting that the presence – or the absence – of morphemes in a new word does not appear to influence fixation durations, in contrast to its effect on visual processing as a whole (as measured by NF, GD and TD).

The absence of an item-type  $\times$  exposures interaction for NF and FTFD suggests that processing times decreased similarly for both types of pseudowords across exposures (respectively,  $\beta = 0.04, z = 0.80, p = .424$ ;  $\beta = -3.27, t = -0.51, p = .612$ ). Nevertheless, there was an interaction effect for GD, TD and STFD (respectively,  $\beta = 29.37, t = 4.27, p < .001$ ;  $\beta = 23.28, t = 3.82, p < .001$ ;  $\beta = 20.52, t = 3.24, p = .001$ ) and a trend towards one for SFD ( $\beta = -11.83, t = -1.81, p = .071$ ). This suggests that there were eye movement variations across exposures depending on item type. Indeed, there were faster decreases in GD, TD and STFD for orthographically complex than for morphologically complex pseudowords, and SFD tended to be higher for orthographically complex than for morphologically complex pseudowords between the three first exposures and the final exposure. Finally, FTFD did not depend on initial bi- or trigram log-frequency ( $\beta = -2.13, t = -1.04, p = .298$ ). However, the higher the latter, the lower the GD, TD and STFD (respectively,  $\beta = -11.80, t = -5.29, p < .001$ ;  $\beta = -15.97, t = -5.74, p < .001$ ;  $\beta = -5.34, t = -2.45, p = .014$ ). These results suggest that frequency of the beginning of the

pseudoword impacted visual processing. In contrast, results showed longer SFD for higher initial bi- or trigram log-frequency ( $\beta = 5.58, t = 2.06, p = .039$ ).

Finally, results related to gaze position are presented Table 1. In contrast with processing times, we observed a main effect of the number of exposures only on SFP ( $\beta = -0.31, t = -4.48, p < .001$ ; FTFP:  $\beta = 0.05, t = 0.97, p = .333$ ; STFP:  $\beta = -0.12, t = -1.60, p = .114$ ). These show that gaze position shifts to the right of the target pseudowords across exposures, with a similar shift when this is the first or second of two fixations. There was no main effects of item type on gaze position (SFP:  $\beta = -0.19, t = -1.09, p = .276$ , FTFP:  $\beta = -0.11, t = -0.87, p = .383$  and STFP:  $\beta = -0.19, t = -1.14, p = .257$ ) suggesting that there were no differences in location of fixations for morphologically complex and orthographically complex pseudowords. Interestingly, across exposures for trials with two fixations, there was a trend towards an item-type  $\times$  exposures interaction effect (FTFP:  $\beta = -0.21, t = -1.95, p = .051$ ); this showed that first fixation position tends to shift to the left of the string between the second and third exposure during the processing of morphologically complex pseudowords, while it systematically shifted to the right of the string during the processing of orthographically complex pseudowords. No interaction effect was found neither for SFP nor for STFP (respectively,  $\beta = -0.13, t = -0.95, p = .343$  and  $\beta = 0.10, t = 0.65, p = .516$ ). Finally, the effect of initial bi- or trigram log-frequency effect was not significant (all  $p_s > .250$ ), except for SFTP ( $\beta = -0.25, t = -4.45, p < .001$ ), suggesting that landing position was not influenced by this variable.

Together these results suggest that there is differential visual processing during learning; morphological complexity facilitates the processing of pseudowords, reflected by shorter visual processing times (i.e., GD, TD and consequently, NF) for the whole pseudoword during the early stages of orthographic learning. This facilitatory effect disappears over exposures, with some

evidence that, after only a few encounters with a pseudoword, the presence of morphemes appears to not only guide gaze position, but also leads to an increase in processing time.

***Stronger Learning of Morphologically and Orthographically Complex Pseudowords***

Results from both the dictation and orthographic choice tasks addressed our second research question as to whether there are differences in the strength of learning of morphologically and orthographically complex pseudowords. For the dictation task, morphologically complex pseudowords were spelled more accurately than orthographically complex pseudowords ( $\beta = -0.64$ ,  $z = -2.13$ ,  $p = .033$ ; 40.6% and 26.4%, respectively), with no main effect of initial bi- or trigram log-frequency ( $\beta = 0.09$ ,  $z = 0.83$ ,  $p = .407$ ). These results suggest that morphological structure facilitates the learning of precise orthographic representations of pseudowords, independently of their initial word frequency.

In the orthographic choice task, linear models (lm function) first showed that participants performed above chance (25 %) for target orthographically and morphologically complex pseudowords that they read in stories (respectively,  $\beta = 42.33$ ,  $t = 14.02$  and  $\beta = 48.58$ ,  $t = 16.39$ ,  $p_s < .001$ ). As further evidence of learning, orthographically and morphologically complex pseudowords read during the orthographic learning task were recognized more accurately than new pseudowords testing transfer ( $\beta = 0.78$ ,  $z = 5.37$ ,  $p < .001$ ) and required longer visual processing time ( $\beta = 108.97$ ,  $t = 5.93$ ,  $p < .001$ ). Comparing results related to orthographically and morphologically complex pseudowords learned through stories, results revealed that accuracy did not depend on item type ( $\beta = -0.36$ ,  $z = -1.34$ ,  $p = .180$ ). Further, in line with results from the dictation task, there was no main effect of initial bi- or trigram log-frequency on gaze duration ( $\beta = 2.37$ ,  $t = 0.33$ ,  $p = .744$ ) nor accuracy ( $\beta = -0.01$ ,  $z = -0.12$ ,  $p = .903$ ). Interestingly, eye movement data (see Table 2) provided additional insight. There was a significant main effect

of item type on TD, that is, times were longer for orthographically complex than for morphologically complex pseudowords ( $\beta = 75.4, t = 2.85, p = .004$ ).

Together these results suggest stronger learning of morphologically than orthographically complex pseudowords, with greater accuracy in spelling of morphologically than orthographically complex pseudowords, when testing on a dictation task. Morphologically complex pseudowords also require less visual processing to be recognized accurately, although there were no differences in accuracy on this task.

### *Transfer of Learning*

Our final research question was whether participants transfer their learning of pseudowords to facilitate the processing of other pseudowords, that are either morphologically or orthographically related. To answer this question, we analyzed accuracy and gaze duration data for the orthographic choice task. We focused on performance in the conditions testing processing of pseudowords that were either morphologically (MT) or orthographically (OT) related to pseudowords read during the orthographic learning task. Table 2 summarizes accuracy and total gaze duration on target items from the orthographic choice task (see columns 3 and 4 for MT and OT results). Statistical analyses of total gaze duration were conducted on correct responses only, leading to us consider 1142 out of 2112 trials in our analysis.

Linear models (lm function) showed that participants performed above chance (25 %) for OT and MT items (respectively,  $\beta = 29.55, t = 11.98$  and  $\beta = 29.97, t = 11.39, p_s < .001$ ), pointing to the fact that readers did transfer their learning. Beyond this, we tested whether the extent of transfer to new pseudowords differed on the presence of morphological structure. We did not detect a statistical difference in accuracy between OT and MT items ( $\beta = -0.02, z = -0.17, p = .868$ ), nor a difference in total gaze duration (i.e., the sum of all fixation durations that

occurred on the target pseudowords;  $\beta = -2.05$ ,  $t = -0.10$ ,  $p = .923$ ). There was also no effect of initial bi- or trigram log-frequency on total gaze duration ( $\beta = -3.34$ ,  $t = -0.44$ ,  $p = .660$ ). These findings suggest that transfer occurs, yet to a similar extent for the identification of accurate spellings of morphologically and orthographically complex words including similar processing times.

### Discussion

In the present study, we examined adults' processing, learning and transfer of learning of morphologically and orthographically complex pseudowords that they read aloud in short stories. This work extends earlier studies by focusing on complex words, shifting from the traditional dominance of simple words in the orthographic learning literature, as well as in integrating eye-movement methods. In our study, adult English-speakers read short stories containing four instances of 16 morphologically or orthographically complex pseudowords, followed by outcome measures of dictation and orthographic choice tasks. This design enabled us to explore differential processing and/or learning of morphologically versus orthographically complex pseudowords. We also evaluated whether morphological structure influenced the degree to which English speaking adults transfer their learning of pseudowords.

Our first question was whether there was an effect of morphological structure on participants' visual processing of pseudowords that they read repeatedly in texts. A first set of findings revealed that participants required more fixations and longer processing times – in both gaze duration and total duration – to process orthographically over morphologically complex pseudowords, suggesting that morphological structure might facilitate information gathering of the letters that compose a new word. These observations contrast with prior evidence of longer



processing times for polymorphemic rather than for monomorphemic known words (Hyönä et al., 2018). Notably, this discrepancy could result from differences in the processing of unknown versus known words. In our study, we observed a faster decrease for orthographically over morphologically complex pseudowords in gaze duration and single fixation duration, reflecting early processing (Pagán & Nation, 2019), and also in total duration and second-of-two fixation duration which is associated with later processing (Mousikou & Schroeder, 2019). As such, our results suggest that during the very first stages of orthographic learning, both early and later visual processing times decrease as a function of morphological complexity, while the presence of suffixes increases processing difficulty after few encounters. Polymorphemic pseudowords involving the processing of semantic clues, recruiting higher-level cognitive processes (Hyönä et al., 2018) and, likely only taking place once efficient orthographic representations are established in memory. Thus, further studies examining the transition in lexical status, from unknown to known words, are important.

Another set of findings are more tentative but allude to additional differences in processing based on morphological structure. When one fixation occurred, gaze position shifted to the right across exposures for both word types. However, when two fixations occurred, gaze positions shifted differently across exposures for morphologically and orthographically complex pseudowords. The first-of-two fixation position shifted to the beginning of morphologically complex pseudowords (in our case, closer to the prefix), whereas it gets closer to the optimal viewing position of the orthographically complex pseudowords (O'Regan & Jacobs, 1992). The second-of-two fixation position shifted to the end of the string regardless of word type. Like Hyönä et al. (2018), we argue that our results demonstrate “an effect of high-level cognitive processes on saccade-target selection during reading” (p. 126). Interestingly, this aligns with our

observation of increases in later visual processing times (i.e., STFD) across exposures. Thus, with enhanced orthographic representation, eye movements are increasingly guided by morphological structure.

Second, we found several points of evidence for stronger learning of the spellings of pseudowords read in story contexts when these were morphologically complex pseudowords than when they were not. Morphologically complex pseudowords were more accurately spelled than orthographically complex pseudowords, and required less time for visual processing in the orthographic choice task. These findings support robust observations that polymorphemic real words are more accurately spelled (e.g., Deacon & Dhooge, 2010) and are read more quickly and accurately (e.g., Deacon et al., 2010) than control words. They also align with some prior studies of eye-tracking in pseudowords, albeit not in an orthographic learning paradigm (Breadmore & Carroll, 2018). Here we extend this pattern to the learning of new pseudowords orthographic representations, also building on Tucker et al. (2016). Notably, accuracy scores from the orthographic choice task revealed no additional effect of morphological structure on orthographic learning. These findings are consistent with Tucker et al. (2016) and point to a potential lack of sensitivity in this task. Overall, participants were better able to learn to spell and were quicker to accurately recognise morphologically over orthographically complex pseudowords, suggesting that the presence of morphological structure in new words facilitates learning of their orthographic form.

Finally, we found that adults transfer their learning of pseudowords to that of other pseudowords, contrasting with the strict item-by-item predictions of the self-teaching hypothesis (Share, 1999). Adults performed above chance in the orthographic choice task for the items testing across both morphological and orthographic complexity. These findings suggest that

orthographic learning is indeed transferred to new words. However, there were no differences based on morphological structure in the extent of learning transfer, as measured by accuracy or visual processing time observed in orthographic choice. Overall, in keeping with findings from Tucker et al. (2016), visual recognition of new pseudowords – reflecting the ability to transfer learning – might not be influenced by their morphological relatedness to learned pseudowords. That said, we did identify effects of morphological structure during the learning process, in keeping with Pacton et al. (2018). As such the presence of morphologically complex words during the learning process itself might strengthen learning with little influence of such structure on later transfer of learning. Further research should continue to evaluate separately the influence of morphological structure on the learning of morphologically complex words versus the transfer of that learning.

This distinction brings forward an important theoretical implication of our research. The distinction between the role of morphological structure in the learning of new words versus the transfer of that learning is not made in the Self-Teaching Hypothesis, the dominant theory of the process of orthographic learning to date. We agree with Tamura et al. (2017) regarding the need to examine both the acquisition of new words into the lexicon and subsequent engagement with those words. In our view, the effect of morphological structure might depend crucially on multiple experiences with words, which enable the accumulation of information about the orthographic structure and the meaning of them, both features central to morphological processing. As such, experience with words may give rise to an effect of morphological structure, and research attending to this experience is likely to more clearly elucidate connections between orthographic learning and the establishment of one's lexicon.

There are several limitations to our work. Our evidence of shorter visual processing times for morphologically complex over orthographically complex (but morphologically simple) pseudowords during the orthographic choice task differs from previous studies on real word processing in sentences. These studies found that gaze duration and first fixation duration increase as a function of morphological complexity (e.g., Hyönä et al., 2018; Inhoff et al., 1996). Contrasting patterns could be due to differences between lexical processing of known and unknown words (e.g., Tamura et al., 2017) or in tasks (Wang et al., 2011). For instance, the dictation task was sensitive to the effects of morphological structure, but there was also quite low accuracy for this task suggesting that more exposures might be needed to learn the orthographic form of long words. Further, effects sometimes diverged in classic behavioural measures and eye-tracking metrics; the latter offered insight into differential visual processing both in outcome metrics and in the process of learning. We also note that our results from the orthographic choice measure point to the need to move beyond this task, even if it is simply towards monitoring looking time within it. On the topic of tasks, future studies could include morphological decoding and awareness (e.g., Deacon et al., 2017), given evidence of individual differences in these (for review see Deacon et al., 2019) that might be relevant to understanding. Finally, in the present study, we focused on first-of-two fixation instead of first-of-multiple fixation (e.g., Joseph et al., 2014). While this limited the analyses to a subsample, results suggested that trials which required exactly two fixations are representative of trials which required two or more fixations. As such, we think that our results are representative beyond this set, while also offering more precise insights into shifts in eye movement during processing.

In summary, we combined a classic self-teaching paradigm with eye-tracking technology to examine adults' processing, learning and transfer of that learning of morphologically and

orthographically complex pseudowords. Eye movement behavior examined on an exposure-by-exposure basis revealed subtle and clear differences in eye movements based on the presence of morphological structure. Further, measures of eye movements, combined with behavioral results, suggest stronger learning of morphologically over orthographically complex pseudowords after just four encounters. Finally, we found clear evidence of transfer of learning to other pseudowords, to a similar extent for both orthographically and morphologically related pseudowords. Our findings open new theoretical and methodological perspectives in the study of cognitive processes implied in orthographic learning and the transfer of that learning.

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### **Conflict of interest statement**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

### References

- Baayen, R. H., Popenbrock, R., & Gulikers, L. (1993). *The CELEX lexical database [CD-ROM]*. Linguistic Data Consortium. <https://catalog.ldc.upenn.edu/LDC96L14>
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68(3), 255-278. <https://doi.org/10.1016/j.jml.2012.11.001>
- Bertram, R. (2011). Eye movements and morphological processing in reading. *The Mental Lexicon*, 6(1), 83–109. <https://doi.org/10.1075/ml.6.1.04ber>
- Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: A critical test of the self-teaching hypothesis. *Journal of experimental child psychology*, 92(3), 203-219. <https://doi.org/10.1016/j.jecp.2005.06.005>
- Breadmore, H. L., & Carroll, J. M. (2018). Sublexical and syntactic processing during reading: evidence from eye movements of typically developing and dyslexic readers. *Journal of Cognitive Psychology*, 30(2), 177-197. <https://doi.org/10.1080/20445911.2017.1414222>
- de Jong, P. F., & Share, D. L. (2007). Orthographic learning during oral and silent reading. *Scientific Studies of Reading*, 11(1), 55-71. <https://doi.org/10.1080/10888430709336634>
- Deacon, S. H., & Dhooge, S. (2010). Developmental stability and changes in the impact of root consistency on children's spelling. *Reading and Writing: An Interdisciplinary Journal*, 23(9), 1055-1069. <https://doi.org/10.1007/s11145-009-9195-5>
- Deacon, S. H., Campbell, E., Tamminga, M., & Kirby, J. (2010). Seeing the harm in harmed and harmful: Morphological processing by children in Grades 4, 6, and 8. *Applied Psycholinguistics*, 31(4), 759-775. <https://doi.org/10.1017/S0142716410000238>

- Deacon, S. H., Tong, X., & Francis, K. (2017). The relationship of morphological analysis and morphological decoding to reading comprehension. *Journal of Research in Reading*, 40(1), 1-16. <https://doi.org/10.1111/1467-9817.12056>
- Deacon, S. H., Tong, X., & Mimeau, C. (2019). Morphological and semantic processing in developmental dyslexia. In C. Perfetti, K. Pugh, & L. Verhoeven (Eds.), *Developmental dyslexia across languages and writing systems* (pp. 327-349). Cambridge University Press.
- Deacon, S. H., Whalen, R., & Kirby, J. R. (2011). Do children see the danger in dangerous? Grade 4, 6 and 8 children's reading of morphologically complex words. *Applied Psycholinguistics*, 32(3), 467-481. <https://doi.org/10.1017/S0142716411000166>
- Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading*, 9(2), 167-188. [https://doi.org/10.1207/s1532799xssr0902\\_4](https://doi.org/10.1207/s1532799xssr0902_4)
- Ginestet, E., Valdois, S., Diard, J., & Bosse, M. L. (2020). Orthographic learning of novel words in adults: effects of exposure and visual attention on eye movements. Advance online publication. *Journal of Cognitive Psychology*, 1-20. <https://doi.org/10.1080/20445911.2020.1823987>
- Hyönä, J., Yan, M., & Vainio, S. (2018). Morphological structure influences the initial landing position in words during reading Finnish. *Quarterly Journal of Experimental Psychology*, 71(1), 122-130. <https://doi.org/10.1080/17470218.2016.1267233>
- Inhoff, A. W., Briihl, D., & Schwartz, J. (1996). Compound word effects differ in reading, on-line naming, and delayed naming tasks. *Memory & Cognition*, 24(4), 466-476. <https://doi.org/10.3758/BF03200935>

- Joseph, H., & Nation, K. (2018). Examining incidental word learning during reading in children: The role of context. *Journal of Experimental Child Psychology*, 166, 190–211.  
<https://doi.org/10.1016/j.jecp.2017.08.010>
- Joseph, H., Wonnacott, E., Forbes, P., & Nation, K. (2014). Becoming a written word: Eye movements reveal order of acquisition effects following incidental exposure to new words during silent reading. *Cognition*, 133(1), 238–248.  
<https://doi.org/10.1016/j.cognition.2014.06.015>
- Li, L., Marinus, E., Castles, A., Yu, L., & Wang, H. (2019). Eye-tracking the effect of semantic decoding on orthographic learning in Chinese. <https://doi.org/10.31234/osf.io/ekxd6>
- Mathôt, S., Schreij, D., & Theeuwes, J. (2012). Opensesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, 44(2), 314–324.  
<https://doi.org/10.3758/s13428-011-0168-7>
- Medler, D. A., & Binder, J. R. (2005). *MCWord: An on-line orthographic database of the English language*. Language Imaging Laboratory Medical College of Wisconsin.  
<http://www.neuro.mcw.edu/mcword/>
- Mimeau, C., Ricketts, J., & Deacon, S. H. (2018). The role of orthographic and semantic learning in word reading and reading comprehension. *Scientific Studies of Reading*, 22(5), 384-400. <https://doi.org/10.1080/10888438.2018.1464575>
- Mousikou, P., & Schroeder, S. (2019). Morphological processing in single-word and sentence reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(5), 881–903. <https://doi.org/10.1037/xlm0000619>



- Nation, K., & Castles, A. (2017). Putting the learning into orthographic learning. In K. Cain, D. L. Compton, & R. K. Parrila (Eds.), *Theories of reading development* (pp. 147–168). Benjamins Publishing Company.
- O'Regan, J. K., & Jacobs, A. M. (1992). Optimal viewing position effect in word recognition: A challenge to current theory. *Journal of Experimental Psychology: Human Perception and Performance*, 18(1), 185–197. <https://doi.org/10.1037/0096-1523.18.1.185>
- Pacton, S., Foulon, J. N., Casalis, S., & Treiman, R. (2013). Children benefit from morphological relatedness when they learn to spell new words. *Frontiers in Psychology*, 4. <https://doi.org/10.3389/fpsyg.2013.00696>
- Pacton, S., Jaco, A. A., Nys, M., Foulon, J. N., Treiman, R., & Peereman, R. (2018). Children benefit from morphological relatedness independently of orthographic relatedness when they learn to spell new words. *Journal of Experimental Child Psychology*, 171, 71–83. <https://doi.org/10.1016/j.jecp.2018.02.003>
- Pagán, A., & Nation, K. (2019). Learning words via reading: Contextual diversity, spacing, and retrieval effects in adults. *Cognitive Science*, 43(1). <https://doi.org/10.1111/cogs.12705>
- Perfetti, C. A. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*, 11(4), 357–383. <https://doi.org/10.1080/10888430701530730>
- Rastle, K., & Coltheart, M. (1999). Serial and strategic effects in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance*, 25(2), 482–503. <https://doi.org/10.1037/0096-1523.25.2.482>
- R Core Team (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>

- Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, 55(2), 151-218. [https://doi.org/10.1016/0010-0277\(94\)00645-2](https://doi.org/10.1016/0010-0277(94)00645-2)
- Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, 72(2), 95-129. <https://doi.org/10.1006/jecp.1998.2481>
- Share, D. L. (2008). Orthographic learning, phonological recoding, and self-teaching. *Advances in Child Development and Behavior*, 36, 31-82. [https://doi.org/10.1016/S0065-2407\(08\)00002-5](https://doi.org/10.1016/S0065-2407(08)00002-5)
- Tamura, N., Castles, A., & Nation, K. (2017). Orthographic learning, fast and slow: Lexical competition effects reveal the time course of word learning in developing readers. *Cognition*, 163, 93–102. <https://doi.org/10.1016/j.cognition.2017.03.002>
- Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (2012). *Test of word reading efficiency second edition*. Pro-Ed.
- Tucker, R., Castles, A., Laroche, A., & Deacon, S. H. (2016). The nature of orthographic learning in self-teaching: Testing the extent of transfer. *Journal of Experimental Child Psychology*, 145, 79-94. <https://doi.org/10.1016/j.jecp.2015.12.007>.
- Wang, H. C., Castles, A., Nickels, L., & Nation, K. (2011). Context effects on orthographic learning of regular and irregular words. *Journal of Experimental Child Psychology*, 109(1), 39–57. <https://doi.org/10.1016/j.jecp.2010.11.005>
- Wilson, M. D. (1988). The MRC Psycholinguistic Database: Machine readable dictionary, version 2. *Behavioral Research Methods, Instruments, & Computers*, 20(1), 6–11. <https://doi.org/10.3758/BF03202594>

- Yan, M., Zhou, W., Shu, H., Yusupu, R., Miao, D., Krügel, A., & Kliegl, R. (2014). Eye movements guided by morphological structure: Evidence from the Uighur language. *Cognition*, 132(2), 181-215. <https://doi.org/10.1016/j.cognition.2014.03.008>
- Ziegler, J. C., Stone, G. O., & Jacobs, A. M. (1997). What is the pronunciation for -ough and the spelling for /u/? A database for computing feedforward and feedback consistency in English. *Behavior Research Methods, Instruments & Computers*, 29(4), 600–618. <https://doi.org/10.3758/BF03210615>

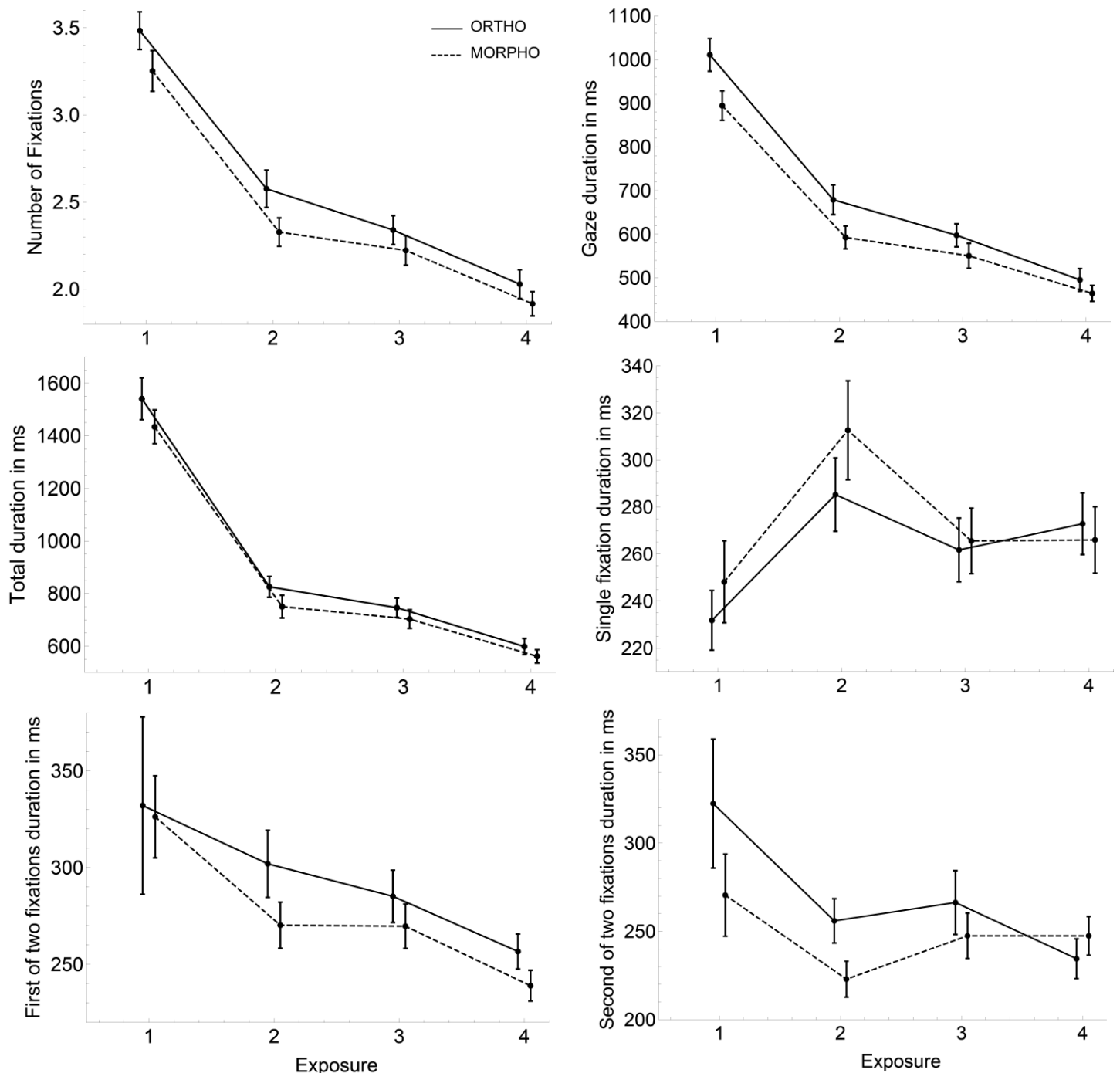


Figure 1

*Eye movement measures recorded during the orthographic learning task as a function of the number of exposures. Are represented, from top to bottom and from left to right: Number of Fixation (NF), Gaze Duration (GD), Total Duration (TD), Single Fixation Duration (SFD), First-of-Two Fixation Duration (FTFD) and Second-of-Two Fixation Duration (STFD). All times are in ms and vertical bars are for standard errors.*

Table 1

*Mean (and Standard Deviations) for Eye Movement Data from the Orthographic Learning Task as a Function of Item Type and Number of Exposures*

Item type		O				M			
Exposure	1	2	3	4	1	2	3	4	
SFP	2.12	2.60	2.85	3.31	2.43	2.84	2.85	3.27	
	(1.29)	(1.27)	(1.53)	(1.79)	(1.47)	(1.39)	(1.35)	(1.04)	
FTFP	2.10	2.41	2.43	2.56	2.54	2.80	2.36	2.27	
	(1.27)	(1.09)	(1.21)	(1.31)	(1.11)	(1.23)	(1.17)	(1.09)	
STFP	4.49	5.41	5.40	5.45	4.47	5.15	5.37	5.33	
	(2.06)	(1.69)	(1.35)	(1.31)	(1.80)	(1.60)	(1.33)	(1.23)	

*Note.* O: orthographically complex; M: morphologically complex Gaze positions (SFP: Single Fixation Position; FTFP: First-of-Two Fixation Position; STFP: Second-of-Two Fixation Position) correspond to the position of the fixated letter in the string (continuous value).

Table 2

*Accuracy and Total Duration Obtained in the Orthographic Choice Task as a Function of Item Type*

	O	M	OT	MT
Accuracy (SD) in %	67.3 (20.0)	73.6 (19.7)	54.5 (16.4)	55.0 (17.4)
Total Duration (SD) in ms	1,041 (375)	977 (325)	1,093 (512)	1,045 (393)

*Note.* O: orthographically complex; M: morphologically complex; OT: orthographically related; MT: morphologically related. Standard deviations are specified in brackets.