Phonological Parafoveal Pre-processing in Children Reading English Sentences

Sara V. Milledge[1], Chuanli Zang[1,2], Simon P. Liversedge[1], and Hazel I. Blythe[3]

[1] School of Psychology and Computer Science, University of Central Lancashire

[2] Faculty of Psychology, Tianjin Normal University

[3] Department of Psychology, Northumbria University

Author Note

The authors declare no conflicts of interest.

The data that supports the findings of this study, and the code used for the main model analyses, are available from https://osf.io/83nxj/?view_only=e3bad0299e9a45e1bea65b64b56085a8.

Correspondence concerning this article should be addressed to Hazel I. Blythe, Northumberland Building, Northumbria University, Newcastle, NE1 8ST. Email: hazel.blythe@northumbria.ac.uk

Abstract

Although previous research has shown that, in English, both adult and teenage readers parafoveally pre-process phonological information during silent reading, to date, no research has been conducted to investigate such processing in children. Here we used the boundary paradigm during silent sentence reading, to ascertain whether typically developing English children, like adults, parafoveally process words phonologically. Participants' eye movements (adults: $n = 48$; children: $n = 48$) were recorded as they read sentences which contained, in preview, correctly spelled words (e.g., *cheese*), pseudohomophones (e.g., *cheeze*), or spelling controls (e.g., *cheene*). The orthographic similarity of the target words available in preview was also manipulated to be similar (e.g., *cheese*/*cheeze*/*cheene*) or dissimilar (e.g., *queen*/*kween*/*treen*). The results indicate that orthographic similarity facilitated both adults' and children's pre-processing. Moreover, children parafoveally pre-processed words phonologically very early in processing. The children demonstrated a pseudohomophone advantage from preview that was broadly similar to the effect displayed by the adults, although the orthographic similarity of the pseudohomophone previews was more important for the children than the adults. Overall, these results provide strong evidence for phonological recoding during silent English sentence reading in 8- to 9-year-old children.

Keywords: reading, parafoveal pre-processing, children, English, phonology, orthography

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1.1 Introduction

Phonology (the pattern of speech sounds within a language) plays a key role in children's literacy acquisition (e.g., Share, 1995). Typically, learning to speak precedes learning to read; it is during learning to read that orthography (words' printed forms) is associated with pre-existing cognitive lexical entries that contain both phonological and semantic (meaning) information (Frost, 1998). It is widely accepted that processing of phonology is a critical component of learning to read. Phonological decoding (the overt, effortful, sounding out of letter sounds) is acknowledged as a vital early phase of reading acquisition (e.g., Ehri, 2007; Frost, 1998; Share, 1995). A pervasive question, therefore, within reading research is the extent to which phonology plays a role in word (lexical) identification, and how this may change through the development from beginning to skilled reader (for a recent review see Milledge & Blythe, 2019). Whilst it is known that phonology is important for children learning to read, much less is known about what happens when they become skilled enough to read silently and independently. In the present study, we examined the extent to which beginner 8- to 9-year-old readers of English were able to process phonological cues from an upcoming word during silent sentence reading, in comparison to skilled English adult readers.

Phonology clearly plays an important role in skilled adult readers' lexical identification processes; such readers have been shown to undertake phonological recoding (the covert, rapid pre-lexical processing of a word's phonology, that is, phonology becoming activated during lexical identification) (Leinenger, 2014). The clearest evidence for pre-lexical phonological processing in adults comes from research investigating parafoveal pre-processing. Adult readers do not only process the word they are directly fixating (*n*) but also begin to process some information about the upcoming word (*n*+1) prior to direct fixation (e.g., Rayner, 1998, 2009). This means that when word *n*+1 is eventually fixated, reading times are faster due to the processing the reader has already undertaken in relation to that word (see Schotter et al., 2012 for a review). This is referred to as parafoveal pre-processing, and it is typically examined using the boundary paradigm (Rayner, 1975). This paradigm allows researchers to manipulate the characteristics of the preview letter string in relation to the target word to examine the types of information that readers are able to process in the parafovea, and how such processing facilitates subsequent lexical identification. Faster reading times on the target word following a related preview compared to an unrelated preview letter string is referred to as preview benefit.

Research using this paradigm has shown that during silent sentence reading, skilled adult readers use phonological codes to aid lexical identification of word *n*+1; they phonologically process the upcoming word (Leinenger, 2014; Milledge & Blythe, 2019; Vasilev et al., 2019). For example, both Chace et al. (2005) and Pollatsek et al. (Experiment 2; 1992) found that adult readers displayed faster reading times on a correct target word when a homophone (e.g., *beech* as a preview for *beach*) was present in preview before the readers' eyes crossed the boundary, compared to a spelling control preview (e.g., *bench* as a preview for *beach*). Interestingly, recent research has shown that such effects (i.e., faster reading times on words due to phonological and orthographic preview similarity, compared to previews with no orthographic or phonological overlap) are even evident cross-script in Russian-English bilinguals (Jouravlev & Jared, 2018).

Moreover, Pollatsek et al. (1992) also found that orthographic similarity of the preview to the correct target word affected participants' pre-processing of phonology: the greater the orthographic overlap between the correct target word and its homophone preview, then the shorter the reading times on the target word (e.g., *paste* as a preview for *paced* resulted in faster reading times than *shoot* as a preview for *chute*). Pollatsek et al. posited, therefore, that phonological and orthographic (graphemic) codes jointly aid lexical identification of an upcoming word. Thus, the facilitatory effects they observed were a function of both the orthographic and phonological overlap of the previews, suggestive of an interactive relationship between orthography and phonology within parafoveal pre-processing. This interactive effect has also been reported in several other studies (e.g., Blythe et al., 2018, 2020). What exactly drives this interactive relationship, though, has never fully been explained.

We suggest that the importance of the first letter of an upcoming word in preview could be critical in respect to why phonological pre-processing is modulated by orthographic similarity, given that the reader's generation of a phonological code necessitates serial left-to-right processing of the letters within a word. Past research has shown that the first letter plays a vital role in skilled adult readers' ability to lexically identify a word, both under direct fixation and, critically, during parafoveal pre-processing (e.g., Briihl & Inhoff, 1995; Hand et al., 2012; Inhoff, 1987, 1989a,b; Johnson & Eisler, 2012; Johnson et al., 2007; Milledge et al., 2021; White et al., 2008). In the studies that report an interaction between orthography and phonology in preview, it is typically shown that the advantage of having phonological information preserved in preview is greater when the orthographic manipulation involves fewer letter substitutions (orthographically similar) than when it involves more letter substitutions (orthographically dissimilar) (see Table 1).

Preview type	Orthographically similar	Orthographically dissimilar
Identity (correct target word)	foul	chute
Homophone	fowl	shoot
Spelling control	foil	shout

Table 1

Example Stimuli from Past Research that has Shown an Interaction between Orthography and Phonology in Preview (e.g., Pollatsek et al., 1992)

As the example in Table 1 shows, the number of letter substitutions is carefully controlled across the homophone and the spelling control (e.g., four out of five letters, in the same within-word locations, are substituted to form both *shoot* and *shout* from the target word *chute*). The manipulations designated as orthographically dissimilar typically involve both more letter substitutions and, very importantly in relation to our suggestion, often substitute the first letter of the word. For example, Pollatsek et al. (1992) found that, within first fixation duration, on average, adults did not show as much benefit from phonology (a homophone), over a spelling control, when the first letter was substituted in preview (e.g., first letter *c* substituted with *s* in preview; *shoot – chute*) compared to when the first letter was maintained in preview (20 ms benefit vs. 37 ms benefit, respectively). In addition, for homophone previews that maintained the first letter, first fixation durations, on average, were more comparable with the identity previews (11 ms cost), in comparison to the homophone previews that substituted the first letter (24 ms cost). We suggest that preserving the orthographic code of the first letter of a word in preview facilitates the extraction of phonological information from the parafovea and lexical identification of a word in adult readers.

Research has also shown that typically developing teenagers are able to pre-process phonology (Blythe et al., Experiment 2; 2018, 2020). Within both studies, teenagers displayed evidence of a pseudohomophone advantage (faster reading times on a pseudohomophone preview compared to a spelling control preview). Moreover, similar to the results of Pollatsek et al. (1992), it was also found that orthographic similarity played a role in the teenagers' pre-processing: previews that were orthographically similar to the correct target word (e.g., *cherch/charch* as previews for *church*) resulted in faster reading times than orthographically dissimilar previews (e.g., *kween/treen* as previews for *queen*). Phonology clearly plays an important role in pre-lexical processing during silent sentence reading, albeit contingent on the degree of orthographic similarity, facilitating both adult and teenage readers' pre-processing of word *n*+1.

As yet, no eye movement research has examined whether beginner child readers of English also pre-lexically process phonology in the parafovea, similar to skilled adult and teenage readers. Two pieces of research, though, have shown evidence of children processing phonology during direct fixation. Blythe et al. (2015) provide evidence of this in children as young as 7-years-old. Blythe et al. recorded the eye movements of 7- to 9-year-old children, and adults, as they silently read sentences that contained a correct target word (e.g., *water*), a pseudohomophone (e.g., *worta*), or a spelling control (e.g., *wecho*). Both the adult and child participants displayed significantly faster reading times when a pseudohomophone was present compared to a spelling control; suggesting that the valid phonology of the pseudohomophone facilitated their lexical identification. Similarly, Jared et al. (Experiment 3; 2016) have also shown that 10- to 11-year-olds use phonological codes to access a word's lexical representation during silent sentence reading. The children read sentences that contained either a correct target word (e.g., *whether*), a homophone (e.g., *weather*), or a spelling control (e.g., *winter*). Critically, the children displayed faster reading times when the homophone was present in a sentence compared to the spelling control. During silent sentence reading, therefore, phonology appears to play a key role in children's lexical identification. In both of these studies, though, phonological processing occurred during direct fixation of the pseudo/homophones. All of this said, it remains unknown whether phonological processing plays a role in pre-lexical processing of a word in the parafovea in beginner readers of English.

Recent research, though, has shown that child readers of English are sensitive to orthographic information in the parafovea. Pagán et al. (2016) found that 8- to 9-year-old children were similarly affected to adults by letter substitutions and transpositions in preview, in regard to both time course and magnitude of effects. Similarly, Milledge et al. (2021) also found that 8- to 9-year-old children, like adults, were sensitive to letter substitutions in preview across the whole-word form (six letters), and, more specifically, external letter substitutions in preview (e.g., *savber*/*numtoc* as previews for *number*) were more harmful to both the adults' and the children's processing than internal letter substitutions in preview (e.g., *navter*/*nuvtor* as previews for *number*). Moreover, an early first-letter bias was found, such that reading times were longer when the first letter of a word was substituted in preview compared to when the end letter was substituted in preview. In addition, Johnson et al. (2018) found that child readers (6- to 12-year-olds) are sensitive to orthography in preview, as they displayed longer reading times when an orthographically dissimilar letter string was present in preview (e.g., *esium* as a preview for *ocean*) compared to an orthographically similar preview (e.g., *ocium* as a preview for *ocean*). Moreover, both of these previews came at a cost to processing relative to the identity condition (where no display change occurred). Overall, this research clearly demonstrates that, similar to skilled adult readers, children from the age of 8 years pre-process the orthography of word n+1 as an integral aspect of lexical processing during sentence reading, such that there is a cost to the efficiency of their lexical processing if such pre-processing is disrupted. Whilst, however, it is known that orthography plays a role in children's parafoveal pre-processing, it is unknown whether orthography modulates phonological pre-processing in children, as is the case for adults (Pollatsek et al., 1992).

There are a number of theories of word recognition that posit how both orthography and phonology might contribute to lexical identification (e.g., Coltheart et al., 2001; Grainger & Ziegler, 2011; Perry et al., 2007). These theories typically focus upon isolated word recognition that occurs when a word is under direct fixation. Whilst these theories do not directly offer any account of the role of parafoveal processing in lexical identification, they do still have the potential to provide insight into the nature of such processing as it occurs during natural reading. For example, Pagán et al. (2016) argued that the letter position encoding effects they observed in parafoveal preview during sentence reading were consistent with the theory offered by Grainger and Ziegler (2011). Grainger and Ziegler proposed that both phonological and orthographic characteristics of lexical stimuli exert an influence in lexical identification via two processing routes: a coarse-grained processing route and a fine-grained processing route. The coarse-grained route allows semantic information to be directly accessed from orthographic form and permits some flexibility with regard to orthographic encoding (i.e., misspellings can be tolerated). The fine-grained route allows access to semantics via commonly co-occurring letter patterns being processed and mapped onto their corresponding phonological representations. Within this route, though, there is little flexibility with regard to orthographic encoding- the first letter's correct orthographic code being present could be especially important to this processing, enabling efficient processing of phonological code(s). According to this theory, early in reading acquisition, children are not expected to show rapid, pre-lexical influences of phonology during word recognition (i.e., they would not display phonological recoding). However, as their age and reading skill increases, children should show a decrease in their reliance on phonological decoding (the slow, laborious, serial sounding out of letter sounds) and an increased reliance on coarse-grained processing, along with fine-grained processing that allows phonological recoding.[1] This fine-grained processing has been evidenced in adult and teen readers (Blythe et al., 2018, 2020; Pollatsek et al., 1992); both groups have been shown to pre-process phonology from word *n*+1 (phonological recoding) and, importantly, this was modulated by orthographic similarity. Orthographically dissimilar previews would be expected to disrupt processing within the fine-grained route due to the greater discrepancy between orthographic and phonological information (given the fine-grained route's limited tolerance for word misspellings; e.g., as at least two letters were substituted in preview and, importantly, half of the previews involved at least the first letter being substituted). In contrast, the orthographically similar previews would be expected to cause less disruption to processing within the fine-grained route as only one letter was manipulated in preview. Critically, within the orthographically similar previews the first letter was never substituted.

With regards to children, Grainger and Ziegler's (2011) theory raises the question of whether there is a point in reading development when phonological decoding is not used but rapid phonological processing is not yet fully developed and efficient, as it is for adult and teenage readers. If this is the case, it is possible that whilst children might display benefits from phonology under direct fixation (Blythe et al., 2015; Jared et al., 2016), they might not be able to process phonology as rapidly as is required within parafoveal pre-processing (i.e., 8- to 9-year-olds might not be able to extract phonological codes from word *n*+1).

Research has shown that typically developing child readers of German are able to process phonological codes from preview. Tiffin-Richards and Schroeder (2015) found that

[1] Note that what Grainger and Ziegler (2011) refer to as phonological recoding, is referred to as phonological decoding within the present paper.

children displayed faster reading times on a target word after a pseudohomophone preview compared to a spelling control preview (a pseudohomophone advantage). Interestingly, though, their adult participants did not display a pseudohomophone advantage; in contrast to the consistent finding of such an advantage within English (e.g., Chace et al., 2005; Pollatsek et al., 1992). This is probably due to the orthographic depths of the two languages and how they differ with regard to how consistently graphemes map onto phonemes. Phonological processing effects are stronger within languages with less consistent grapheme to phoneme correspondences (less transparent languages, i.e., English) compared to languages which benefit from more consistent grapheme to phoneme correspondences (i.e., German) (Ziegler et al., 2010). Critically, of central importance to this paper, though, Tiffin-Richards and Schroeder (2015) did not investigate whether there is an interaction between orthography and phonology in preview. Indeed, due to the transparency of German's orthography, it may not be possible to create pseudohomophone previews that do not have a high degree of orthographic overlap with a target word (though we note that some of Tiffin-Richards and Schroeder's stimuli did manipulate orthographic form in preview; e.g., *Baan* vs. *Baen* as previews for *Bahn*).

In the present study, we examined parafoveal pre-processing of phonology and orthography in a typical population of 8- to 9-year-old native readers of English, in comparison to a group of skilled adult readers. We manipulated the orthographic and phonological features of the target words in preview, using the boundary paradigm (Rayner, 1975), with the following manipulations: (1) phonological similarity; and (2) orthographic similarity. The type of target word participants were presented with in preview formed our independent variable, with five levels: preview type- identity; orthographically similar pseudohomophone; orthographically dissimilar pseudohomophone; orthographically similar spelling control; orthographically dissimilar spelling control (see Table 2).

Preview type	Orthographic similarity	Example
Identity (correct target word)		church
Pseudohomophone	Orthographically similar	cherch
Spelling control	Orthographically similar	charch
Identity (correct target word)		circle
Pseudohomophone	Orthographically dissimilar	sercle
Spelling control	Orthographically dissimilar	norcle

Table 2

Experimental Design

With respect to our dependent variables, we expected any effects that were likely to be present would be within earlier measures of processing (first fixation duration, single fixation duration, and gaze duration; e.g., Blythe et al., 2018, 2020; Pollatsek et al., 1992; Vasilev et al., 2019). As such, these three measures constitute the reading time measures we refer to within our predictions below.

First, we predicted overall group differences, such that the children would display longer reading times on the target words in comparison to the adults (e.g., Häikiö et al., 2010; Milledge et al., 2021; Pagán et al., 2016; Tiffin-Richards & Schroeder, 2015). Second, we predicted that, for both participant groups, nonword previews would lead to longer reading times than the correct (identity) previews (e.g., Johnson et al., 2018; Pagán et al., 2016; Pollatsek et al., 1992). Third, we predicted that faster reading times would result from orthographically similar previews compared to orthographically dissimilar previews; adult readers are sensitive to orthographic information in preview (e.g., Balota et al., 1985; Binder et al., 1999; Johnson & Dunne, 2012), as are child readers as young as 8-years-old (e.g., Johnson et al., 2018; Milledge et al., 2021; Pagán et al., 2016).

The predictions for the key manipulation of phonology were more complex and differed for the two participant groups. With respect to adults, we predicted a pseudohomophone advantage from parafoveal pre-processing (faster reading times on the target word after a pseudohomophone preview compared to a spelling control; e.g., Blythe et al., 2018, 2020; Leinenger, 2019). We also predicted that this advantage would be modulated by orthographic similarity; specifically, that the pseudohomophone advantage would be observed in the orthographically similar condition, where the first letter of a target word was maintained, but absent within the orthographically dissimilar condition (e.g., Blythe et al., 2018, 2020; Pollatsek et al., 1992).

For children, no research has, to date, examined whether English readers aged 8-9 years are sensitive to phonology during parafoveal pre-processing. For this reason, we were unable to confidently predict whether they would show a pseudohomophone advantage or not. Similarly, we were unable to confidently predict whether any possible pseudohomophone advantage might be modulated by orthographic similarity. This said, one might reasonably anticipate that processing might be comparable in children as in adults, though with a slower time course (Milledge et al., 2021). Obtaining interactive effects that pattern comparably to the predicted effects in adults within the 8- to 9-year-old child readers would not only be indicative of phonological recoding being undertaken, but also of fairly sophisticated parafoveal pre-processing occurring whereby phonological codes are accessed from orthographic codes via a fine-grained route of processing (Grainger & Ziegler, 2011).

1.2 Method

1.2.1 Participants

Forty-eight adults (*M* = 21.02 years old; *SD* = 3.56) from the University of Southampton community and 48 children (aged 8- to 9-years-old; *M* = 8.31; *SD* = .47) from a local junior school participated in the eye-tracking experiment. All participants had normal or corrected to normal vision, and were native speakers of English with no known reading difficulties, as confirmed by the reading subtests of the Wechsler Individual Achievement Test II UK (WIAT-II UK; Wechsler, 2005). The participants did not significantly differ with regard to their standardised scores on the three reading subtests of the WIAT-II UK (word reading, pseudoword decoding, and comprehension; all ts < 1.59, all ps > .114). All participants' composite standardised scores were within the expected range (adults' score range: 99-139; children's score range: 99-136); though the adults, on average, scored higher (*M* = 119.35, *SD* = 9.78) than the children (*M* = 113.35, *SD* = 8.32; $t(94) = 3.24$, $p = .002$). The significant difference in the composite scores indicates that the children were, for their age, less skilled than the adult readers (perhaps unsurprisingly given the more heterogeneous sample within a state junior school compared to students within a university). Importantly, both participant groups were reading at, or above the expected level, with no evidence of reading difficulties for any individual participant.

All adult participants gave informed written consent prior to participation. Parents provided informed written consent on behalf of their children, and the children also provided their own informed written assent, prior to participation. Ethical approval was provided by the University of Southampton Psychology Ethics Committee (submission ID: 45888).

1.2.2 Materials and Design

We used the stimuli from Experiment 2 reported in Blythe et al. (2018, 2020), comprising of 24 target words and sentence frames (see Appendix A), which had been pre-screened with 78 8- to 9-year-old children. Two manipulations were made: a within-item phonological manipulation, and a between-item orthographic manipulation. Regarding the phonological manipulation, two nonwords were created for each target word to create a triplet of previews: the correctly spelled (identity) preview; a pseudohomophone preview; and a spelling control preview (e.g., *cheese*/*cheeze*/*cheene*). The length of the previews was always matched, and syllabic structure was maintained. The nonword previews had also been matched on orthographic overlap with the identity preview, number of orthographic neighbours, consonant-vowel structure, and word shape (e.g., descenders were substituted with descenders, ascenders with ascenders, etc.).

For the orthographic manipulation, each preview triplet was either orthographically similar (12 triplets) or orthographically dissimilar (12 triplets). Within the orthographically similar triplets, only one letter (never the first or second letter) was substituted to form the two nonword previews. Within the orthographically dissimilar triplets, at least two letters (with one letter at least being the first and/or second letter) were substituted to form the two nonword previews (see Table 3 for example stimuli).

Preview type	Orthographically similar	Orthographically dissimilar
Identity (correct target word)	cheese	queen
Pseudohomophone	cheeze	kween
Spelling control	cheene	treen

Table 3

Examples of Orthographically Similar and Orthographically Dissimilar Stimuli

The correctly spelled (identity condition) target words (12 in each condition) were matched on frequency from an adult corpus (0-1882 per million; Balota et al., 2007) and a child corpus (8-560 per million; Masterson et al., 2003), Age of Acquisition (2.90 - 7.63 years; Kuperman et al., 2012), and orthographic neighbourhood size (0-23) (all ts < 2, all ps >

.1). Both sets of stimuli contained 4-6 letter words (with a marginally significant difference in word length between the two sets of stimuli, $p = .05$).

Three counterbalanced lists of sentences were created, each including either an identity preview, a pseudohomophone preview, or a spelling control preview from each triplet: four of each kind of preview from the orthographically similar stimuli, and four from the orthographically dissimilar stimuli. Consequently, each participant read 24 sentences, comprised of eight sentences with identity previews, eight with orthographically similar previews (four pseudohomophone previews, four spelling control previews), and eight with orthographically dissimilar previews (four pseudohomophone previews, four spelling control previews). The sentences occupied one line on the screen (maximum = 70 characters; $M = 61$ characters; e.g., *Cheddar is my favourite kind of cheese to have for lunch.*).

1.2.3 Apparatus and Procedure

Participants first completed the eye-tracking experiment. An EyeLink 1000 eye-tracker recorded right eye movements (SR Research). Participants were seated comfortably using forehead and chin rests, to minimise head movements, and were instructed to read normally and for comprehension. Then a three-point horizontal calibration and validation procedure was carried out. If the mean validation error, or the errors for any of the individual points, was greater than .20°, then the procedure was repeated. There were four practice trials at the beginning of the experiment (with two comprehension question trials), to ensure that participants were familiar with the procedure. A single sentence was presented at a time in 14-point, black Courier New font on the grey background of a 21 in. CRT monitor, with a refresh rate of 120 Hz, at a 60 cm viewing distance; one character subtended .34° of visual angle. Once participants had finished reading a sentence, they pressed a button on a gamepad, and nine of the sentences were followed by a comprehension question, to which the participants responded (see Appendix A). After completion of the experiment, participants were asked whether they had noticed anything strange about the appearance of the sentences in the experiment: detecting a display change can affect fixation times (e.g., White et al., 2005). Two adult participants reported noticing something unusual about the sentences, even though they could not specify what, so their data were excluded from the analyses. Then participants completed the three reading subtests of the WIAT-II UK (Wechsler, 2005). The whole experiment lasted about 35 minutes per participant.

1.2.4 Power

One of the key results we expected to find was evidence of an interactive effect between orthography and phonology within the adults (i.e., a pseudohomophone advantage within the orthographically similar stimuli but not within the orthographically dissimilar stimuli; see key research question prediction 2). Past research has shown evidence of such an effect within 16-18 year olds using these stimuli: contrasts, comparing orthographically similar pseudohomophone previews to orthographically similar spelling control previews, revealed a slope of -.11 within first fixation duration ($p = .049$), a 21 ms benefit (the "TDO" group from Blythe et al., 2020).[2] Using the *simr* package in R (Green & Macleod, 2016), we calculated our power to detect an effect of phonology within the orthographically similar stimuli in first fixation duration, specifying a slope of -.11 as a reasonable estimate of effect size (note, we did not expect that 16-18 year olds' processing would differ significantly to that of the 18-34 year old adult sample within the present experiment, as both groups should reasonably be considered skilled readers. Measures of eye movement behaviour during reading reach asymptote at approximately 11-12 years; e.g., Blythe & Joseph, 2011; Buswell, 1922; McConkie et al., 1991; Taylor, 1965). Our power to detect a slope of -.11 within first

[2] We based our power analyses on Blythe et al. (2020) due to this study having greater power than Blythe et al. (2018): Blythe et al. (2020) had a greater number of older teenage participants (30 vs. 23). We note that Blythe et al. (2020) do not report these contrasts; they were conducted in R using the datafile that they made available on the OSF for Experiment 2.

fixation duration for the adults was 95% (above 80% is typically considered sufficient; Cohen, 1962). A similar estimate of power was also found within gaze duration (slope: -.12, power: 95.10%).

Regarding the potential for an interactive effect between orthography and phonology within the children, we could not run formal power analyses, as no data set exists from which an effect size could be estimated. We do know, however, that effect sizes for reading time measures in eye movement data are generally larger within younger developmental groups (e.g., Blythe et al., 2018, 2020). For example, within gaze duration in Blythe et al. (2020), whilst the typically developing older teenagers ("TDO" group; $M = 17.25$ years) displayed a phonological parafoveal preview effect size of $d = .18$ (collapsing across orthographic conditions), the typically developing younger teenagers ("TDY" group; $M = 14.75$ years) displayed an effect size of $d = .35$. Similar differences within effect sizes were also present with regard to orthography (collapsing across the pseudohomophone and spelling control previews; $d = .25$ vs. $d = .58$). We are confident, therefore, that if there was an interactive effect between orthography and phonology within the children, our experiment would have sufficient power to determine this, especially given that the present experiment included a greater number of participants than the previous experiments that used these stimuli.

Finally, with respect to issues of power, it was also not possible to run formal power analyses for the three-way interaction term (children × phonology × orthography). Again, this was not possible because there is no existing data set on which we could base effect size estimates. We did not know whether children would differ in their parafoveal pre-processing in comparison to that of the adults (see key research question prediction 3). Given this, and given our wish to proceed in a scientifically cautious manner, we decided that if the three-way interactions were non-significant, they would be treated with caution and tested rigorously using Bayesian analyses.

1.3 Results

All participants scored at least 77% on the comprehension questions (adults: *M* = 97.69%, *SD* = 4.56%; children: *M* = 90.97%, *SD* = 9.07%). The data were trimmed using the clean function in DataViewer (SR Research).[3] In total 884 fixations were merged or deleted (2.22% of the dataset; 385 adult fixations and 499 child fixations), resulting in a final dataset of 38,929 fixations.

1.3.1 Global Measures

Firstly, we examined global measures of participants' eye movement behaviour- their eye movements across entire sentences. As can be seen from Table 4, on average, the children: displayed significantly longer fixation durations than the adult participants, $t(94) = -4.91$, $p < .001$); made significantly more fixations than the adults, $t(94) = -8.63$, $p < .001$); and displayed significantly longer total sentence reading times than the adults, $t(94) = -8.70$, $p < .001$), consistent with past research (e.g., Blythe & Joseph, 2011).

Measure	Adults	Children
Fixation duration (ms)	239 (26)	266 (29)
Fixation count	14 (3)	20 (4)
Total sentence reading time (ms)	3260 (944)	5636 (1642)

Table 4

Mean and Standard Deviation (in parentheses) Values for Measures across Entire Sentences

1.3.2 Local Measures

[3] Fixations less than 80 ms were merged with the neighbouring fixation if within a .50° distance of another fixation over 80 ms. Also, fixations less than 40 ms were merged with neighbouring fixations if within a 1.25° distance of each other. If an interest area had three or more fixations less than 140 ms, these were then merged into longer fixations. Subsequently, all remaining fixations less than 80 ms or greater than 1,200 ms were deleted.

Then, we analysed reading time data on the target word in each sentence. Before analysing the local dependent measures, the data were further cleaned: trials in which the boundary change occurred early during a fixation on the pre-target word, and those that occurred late when the display change was not completed until more than 15 ms after onset of fixation on the target word (e.g., Blythe et al., 2018; Johnson et al., 2018) were excluded from the analyses (110 adult trials- 9.55% of the adult trials, and 140 children's trials- 12.15% of the children's trials). We also operationalised a late boundary change as 5 ms and 10 ms in order to check that our 15 ms criterion was not allowing display change detection "artifacts" (Slattery et al., 2011). Due to the pattern of data remaining unchanged between the three reports, across all measures of interest (as outlined in the paragraph below), the 15 ms criterion was adopted as it allowed the retention of more data (2,054 data points as opposed to 1,922 or 1,526). Regarding the number of items per condition for each participant, after the boundary change cleaning, the lowest total number of items recorded for an adult participant was 17 (M = 21.71, total range: 17-24; identity M = 7.33, range: 5-8; orthographically similar pseudohomophones M = 3.69, range: 1-4; orthographically dissimilar pseudohomophones M = 3.46, range: 2-4; orthographically similar spelling controls M = 3.58, range: 2-4; and orthographically dissimilar spelling controls M = 3.65, range: 2-4) and within the child participants this was also 17 (M = 21.08, total range: 17-23; identity M = 7.13, range: 5-8; orthographically similar pseudohomophones M = 3.35, range: 2-4; orthographically dissimilar pseudohomophones M = 3.50, range: 2-4; orthographically similar spelling controls M = 3.44, range: 2-4; and orthographically dissimilar spelling controls M = 3.67, range: 2-4).

Data were analysed using linear mixed effects (lme) models, using the *lmer* function from the lme4 package (Bates et al., 2015) within the R environment for Statistical Computing (R Core Team, 2020), with participants and items entered as crossed random effects. To avoid being anti-conservative, a full random structure was initially specified for participants and items (Barr et al., 2013). If the models for each dependent measure failed to converge, the random structure was trimmed until they did converge. The standard, key dependent measures were: first fixation duration (the duration of the initial first-pass fixation on a word, regardless of how many fixations the word received), single fixation duration (the time that a word was fixated when it received only one first-pass fixation), and gaze duration (the sum of all fixations on the word before the eyes left it for the first time); see Table 5.[4] Reading time data were log transformed before analysis to reduce skew (e.g., Baayen et al., 2008). In addition, log transforming the data for use within the models made our results directly comparable to past experiments that have examined parafoveal pre-processing within developmental groups (e.g., Blythe et al., 2018, 2020; Johnson et al., 2018; Milledge et al., 2021; Pagán et al., 2016).

[4] The probability of the children making a single fixation across all trials was .65 and the probability of the adults making a single fixation across all trials was .75. Single fixation probabilities for the adults and the children by condition are available in Appendix B (Table B1). Within Appendix B skipping rates are also provided in Table B2. Within the main model analyses, no generalized linear mixed models would converge for this measure. Intercept only models within the contrasts converged but the results were non-significant, *p*s > .311.

Group	Condition	First fixation duration (ms)	Single fixation duration (ms)	Gaze duration (ms)
Adults	Identity	218 (81)	218 (83)	237 (106)
	Orthographically similar pseudohomophones	222 (71)	223 (71)	253 (102)
	Orthographically similar spelling controls	235 (75)	239 (71)	265 (97)
	Orthographically dissimilar pseudohomophones	236 (77)	249 (78)	269 (83)
	Orthographically dissimilar spelling controls	246 (77)	253 (81)	275 (92)
Children	Identity	247 (103)	258 (107)	317 (161)
	Orthographically similar pseudohomophones	252 (93)	267 (99)	329 (173)
	Orthographically similar spelling controls	275 (111)	294 (110)	341 (144)
	Orthographically dissimilar pseudohomophones	307 (128)	330 (128)	363 (139)
	Orthographically dissimilar spelling controls	289 (124)	315 (129)	361 (153)

Table 5

Mean and Standard Deviation (in parentheses) Reading Times on the Target Word in Each Condition

Two lme models were run. Within Model 1 custom contrasts were specified to compare and collapse the nonword preview conditions to the correctly spelled identity preview condition, with participant group included as an interaction. This allowed us to look at the cost associated with a nonword being present in preview, examining whether participants displayed preview benefit, with the children being compared to the adults. Model 2 excluded the correctly spelled identity preview, and only included the nonword preview conditions, again with participant group included as an interaction. This model allowed us to directly examine the main effects of, and interaction between, phonology (pseudohomophones vs. spelling controls) and orthography (orthographically similar vs. orthographically dissimilar) within adults' and children's parafoveal pre-processing.

This two-step approach was used due to the unbalanced nature of this experiment, given the between-items manipulation of orthographic similarity. Whilst the orthographic similarity/dissimilarity split was meaningful regarding the nonword (pseudohomophone and spelling control) previews, this split was not meaningful regarding the correctly spelled target word (identity) previews (i.e., one-third of the stimuli would have been incorrectly classed as orthographically similar or dissimilar). Thus, for Model 1 the data from the identity previews was collapsed into a single condition. Within the two models, effects were considered significant when $|t| > 1.96$.

1.3.2.1 Model 1

The five experimental conditions were coded as: 1) identity previews; 2) orthographically similar pseudohomophone previews; 3) orthographically dissimilar pseudohomophone previews; 4) orthographically similar spelling control previews; and 5) orthographically dissimilar spelling control previews. Group was coded such that adults were the baseline (i.e., coded as 1; children were coded as 2). Contrasts for the main effect of preview benefit (i.e., comparing the nonword previews to identity preview) were specified as -1, .25, .25, .25, .25. As such, the intercept for this model corresponded to the average reading times of the adults on the identity previews. The results of this model, for each of the dependent measures, are shown in Table 6.

	First fixation duration				Single fixation duration				Gaze duration			
	b	SE	*t*	*p*	b	SE	*t*	*p*	b	SE	*t*	*p*
Adults, Identity (Int)	5.39	.03	214.12	< .001	5.41	.03	186.61	< .001	5.49	.03	171.85	< .001
Group (Adults vs. Children)	**.14**	**.03**	**4.74**	**< .001**	**.20**	**.03**	**5.73**	**< .001**	**.25**	**.04**	**7.13**	**< .001**
Identity vs. nonword previews	**.09**	**.03**	**3.72**	**< .001**	**.12**	**.03**	**4.38**	**< .001**	**.15**	**.03**	**4.57**	**< .001**
Children × Identity vs. nonword previews	.03	.03	1.00	.321	.02	.04	.60	.551	-.03	.04	-.69	.494

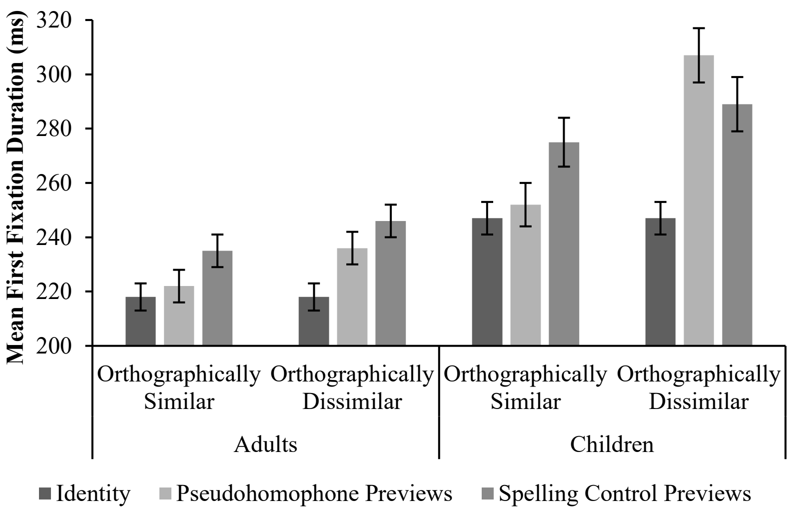
Table 6

Output from Model 1 for First Fixation Duration, Single Fixation Duration, and Gaze Duration

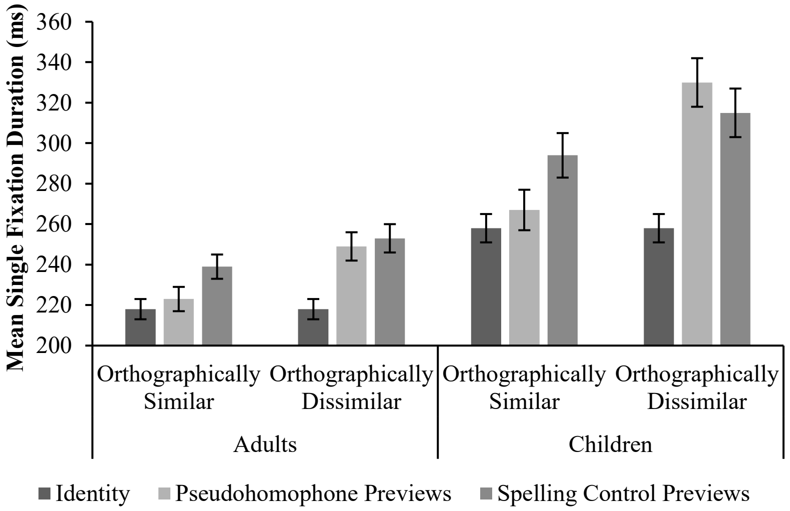
Note. The reading time data were log transformed prior to analysis, so the model estimates cannot be directly interpreted. Significant effects are marked in bold. The full model syntax was as follows: *depvar ~ Group * Condition + (1 + Condition|Participant) + (1 + Group * Condition|targetno)*. Following trimming, the syntax for all measures was as follows: *depvar ~ Group * Condition + (1 + Condition|Participant) + (1 + Group + Condition|targetno)*.

Firstly of note from this model's results, shown in Tables 5 and 6 (see also Figure 1), is that, in all of the measures, the children had longer reading times than the adults. Second, the adults displayed clear preview benefit across all measures: longer reading times on a target word after a nonword preview compared to an identity preview (where no display change occurred). In addition, the lack of interaction suggests that the children's pre-processing was comparable to that of the adults (i.e., they displayed preview benefit).

(a)



(b)



(c)

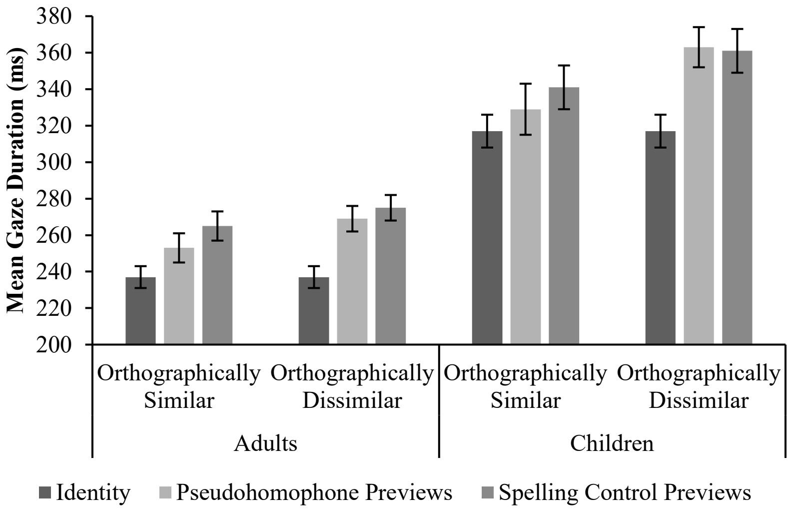


Figure 1

Mean First Fixation Durations (a), Single Fixation Durations (b), and Gaze Durations (c) on Identity, Pseudohomophone, and Spelling Control Previews for Both Adults and Children

1.3.2.2 Model 2

As word length varied (stimuli word length ranged between 4-6 letters), a lme model was run with length as a factor. For all three of the dependent measures, word length had no significant effect, *t*s < +/-1.12. Formal model comparisons were also run to examine word length's role within our data. These comparisons showed, within all dependent measures, that including word length did not improve the fit of our models, *p*s > .181, consequently, we report the models without word length.

In this model, the phonological conditions were coded as: (1) pseudohomophones; and (2) spelling controls. The orthographic conditions were coded as: (1) orthographically similar; and (2) orthographically dissimilar. Contrasts for the factors were specified as -1/1, such that the intercept corresponded to the grand mean and the differences between the two groups and the conditions were examined. The results of this model, for each of the dependent measures, are shown in Table 7.

	First fixation duration				Single fixation duration				Gaze duration			
	b	SE	*t*	*p*	b	SE	*t*	*p*	b	SE	*t*	*p*
Intercept (grand mean)	5.49	.02	280.78	< .001	5.53	.02	226.86	< .001	5.64	.03	219.30	< .001
Group (Adults vs. Children)	**.15**	**.03**	**4.79**	**< .001**	**.19**	**.03**	**5.99**	**< .001**	**.25**	**.03**	**7.67**	**< .001**
Phonological condition	.03	.02	1.64	.101	.04	.02	1.85	.065	.03	.02	1.42	.155
Orthographic condition	**.08**	**.03**	**2.70**	**.013**	**.10**	**.04**	**2.32**	**.030**	.08	.04	1.69	.105
Children × phonological condition	-.04	.03	-1.06	.290	-.02	.04	-.42	.675	-.01	.04	-.25	.801
Children × orthographic condition	.06	.03	1.66	.097	.06	.04	1.44	.150	.02	.04	.60	.552
Phonological condition × orthographic condition	-.07	.03	-1.90	.058	**-.10**	**.04**	**-2.49**	**.013**	-.05	.04	-1.25	.213
Children × phonological condition × orthographic condition	-.12	.07	-1.71	.088	-.04	.08	-.52	.601	-.01	.08	-.13	.897
Contrasts												
Intercept (grand mean)	5.49	.02	245.00	< .001	5.53	.03	198.56	< .001	5.64	.03	192.14	< .001
Adults, orthographically similar previews, pseudohomophone advantage	-.05	.03	-1.49	.138	**-.08**	**.04**	**-2.33**	**.020**	-.05	.04	-1.43	.152
Children, orthographically similar previews, pseudohomophone advantage	**-.07**	**.04**	**-2.01**	**.045**	**-.08**	**.04**	**-2.02**	**.044**	-.05	.04	-1.19	.233

Adults, orthographically dissimilar previews, pseudohomophone advantage	-.04	.03	-1.25	.212	-.003	.04	-.09	.927	-.009	.04	-.25	.804
Children, orthographically dissimilar previews, pseudohomophone advantage	.05	.03	1.42	.156	.02	.04	.62	.535	-.001	.04	-.04	.969

Table 7

Output from Model 2 for First Fixation Duration, Single Fixation Duration, and Gaze Duration

Note. The reading time data were log transformed prior to analysis, so the model estimates cannot be directly interpreted. Significant effects are marked in bold. The full model syntax for Model 2 was as follows: *depvar ~ Group * phoncond * orthcond + (1 + phoncond * orthcond|Participant) + (1 + Group * phoncond|targetno)*. Following trimming, the syntax for all dependent measures for Model 2, as intercepts only models, was as follows: *depvar ~ Group * phoncond * orthcond + (1|Participant) + (1|targetno)*. The contrasts were set up for all of the dependent measures within the following syntax: *depvar ~ Condition2 + (1 + Condition2|Participant) + (1 + Condition2|targetno)*. Following trimming, though, the models were intercepts only for comparing the orthographically similar pseudohomophone previews to the spelling control previews and the orthographically dissimilar pseudohomophone previews to the spelling control previews: *depvar ~ Condition2 + (1|Participant) + (1|targetno)*.

As can be seen in Tables 5 and 7, and Figure 1, again, there were significant group differences in all measures: the children's reading times were significantly longer than those of the adults. In first fixation and single fixation durations both adults and children displayed significantly longer reading times in the orthographically dissimilar preview conditions compared to the orthographically similar preview conditions. Also, in single fixation duration, and marginally in first fixation duration, an interaction was present between the phonological conditions and the orthographic conditions. In single fixation duration both adults and children displayed a pseudohomophone advantage in preview (i.e., faster reading times in the pseudohomophone preview condition compared to the spelling control preview condition) but this was very much affected by orthographic similarity. Orthographic similarity facilitated this pre-processing of phonology, especially for the children: for the orthographically similar stimuli the pseudohomophone advantage for the adults was, on average, 16 ms and for the children it was 27 ms, whilst for the orthographically dissimilar stimuli the pseudohomophone advantage for the adults was 4 ms and for the children they actually displayed, on average, longer single fixation durations on the pseudohomophone previews than the spelling controls by 15 ms. In gaze duration, apart from the overall group differences, no significant effects or interactions were found.

Given the evident effect of orthographic similarity within some of the measures, custom contrasts were specified to directly test for a pseudohomophone advantage in both the adults and the children separately within the two orthographic conditions. For each group, and dependent measure, we compared reading times on the pseudohomophone and spelling control previews in the orthographically similar and dissimilar cases. Contrasts for the preview conditions were specified as 1/-1; the intercept corresponded to the grand mean and the contrasts represented the difference between the two conditions. Within the orthographically similar stimuli, in both first and single fixation durations, the children were displaying a pseudohomophone advantage, and in single fixation duration, the adults similarly benefitted from a pseudohomophone preview being present compared to a spelling control.

Overall, the children were displaying a pseudohomophone advantage in their very early processing of the nonword previews that were orthographically similar to the correctly spelled identity previews (and in the adults this was significant in single fixation duration).

1.3.3 Bayesian Analyses

Of interest within our results was the seemingly null effect of group on condition, and the resultant null interactions. Consequently, Bayesian analyses were conducted to assess the strength of the evidence for the null and alternative hypotheses. The analyses were conducted using the BayesFactor package (Morey & Rouder, 2013), using the default scale value (.5) for the Cauchy priors on effect size and 100,000 Monte Carlo iterations. A low Bayes factor (< 1) indicates evidence for the null hypothesis, whilst a high Bayes factor (> 1) provides evidence for the alternative hypothesis. Within all models items and subjects were specified as random factors. Within Model 1 we examined the null interaction between children and the identity condition versus the nonword preview conditions, comparing one model which had fixed factors of group and condition (*Group* + *Condition*) to a model which additionally had an interaction term between group and condition (*Group* + *Condition* + *Group:Condition*). The Bayes factors from the analyses were .06 for first fixation duration, .01 for single fixation duration, and .002 for gaze duration. Using the commonly cited evidence categories for Bayes factors, where a Bayes factor < .33 provides substantial evidence for a null effect, and a Bayes factor < .10 provides strong evidence, our Bayesian analyses indicate strong evidence for the null hypothesis (i.e., the children's reading times were indeed patterning in a way consistent with the adults' reading times- displaying similar costs to their reading times when nonwords were present in preview compared to when no display change occurred and an identity preview was present).

Within Model 2, due to this model directly examining the key variables of interest, all null interactions were examined. All of the null interactions were examined by comparing a model that contained fixed factors of group and either phonological condition or orthographic condition (e.g., *Group + phoncond*) with a model that additionally contained an interaction term (e.g., *Group + phoncond + Group:phoncond*), and the three-way interaction was examined in a similar way (i.e., a model without the interactive terms was compared to a model with the interactive terms- *Group*phoncond*orthcond*). Regarding phonological condition, our Bayesian analyses indicated substantial evidence for the null hypothesis (.16 for first fixation duration; .12 for single fixation duration; and .09 for gaze duration), and, regarding orthographic condition, again, our analyses indicated substantial evidence for the null hypothesis (.31 for first fixation duration; .27 for single fixation duration; and .10 for gaze duration). Regarding the three-way interaction, our analyses indicated strong evidence for the null hypothesis (.01 for first and single fixation durations; and < .001 for gaze duration). Overall, the results of these Bayesian analyses suggest that the children's parafoveal pre-processing was indeed consistent with that of the adults.

We also examined null effects within our contrasts by comparing a model which coded the nonword preview conditions separately for the adults and the children (*AdultsOrthSim*/*AdultsOrthDissim*/*ChildrenOrthSim*/*ChildrenOrthDissim*) against the default, intercept only model. Our Bayesian analyses indicated evidence for the null hypothesis within the orthographically similar stimuli for the adults (.37 for first fixation duration and .31 for gaze duration). We also found substantial evidence for the null hypothesis within the orthographically similar stimuli for the children in gaze duration (Bayes factor of .27). Similarly, within the orthographically dissimilar stimuli we found substantial evidence for the null hypothesis within both the adults (first fixation duration: .28; single fixation duration: .15; and .13 for gaze duration) and the children (first fixation duration: .29; single fixation duration: .21; and .13 for gaze duration). These results support the absence of a pseudohomophone advantage within the orthographically dissimilar stimuli, within all measures, for both the adults and the children. In addition, the results support the lack of a pseudohomophone advantage within gaze duration for both the adults and the children (within both the orthographically similar and dissimilar stimuli) and for the adults in first fixation duration within the orthographically similar stimuli. In sum, the pseudohomophone advantage was only present within the orthographically similar stimuli, in the early eye movement measures of first and single fixation duration for the children, and single fixation duration for the adults.

1.3.4 Post-hoc Considerations

The stimuli were developed by Blythe et al. (2018), showing effective manipulations that were appropriate for use with children aged 8- to 9-years-old. This latter point is critical as younger children have a substantially smaller vocabulary in comparison to adults. Consequently, there is reduced scope for researchers to make effective manipulations within the set of words that are known to children, compared to the much larger set of words that are known by adults.

The orthographic manipulation within this study was based on that reported by Pollatsek et al. (1992) and Rayner et al. (1998). Using their criteria, the orthographically dissimilar stimuli involved the first and/or second letters of a given word being substituted. We now know, however, that the first letter plays a particularly important role in both adults' and children's parafoveal pre-processing (e.g., Johnson et al., 2007; Milledge et al., 2021). It is possible that, within the orthographically dissimilar stimuli, different patterns may have emerged from stimuli where the first letter was substituted (e.g., *kween*) compared to those where the first letter was preserved (e.g., *sorce*). These two subgroups of stimuli may have differentially affected the extraction of phonological information from preview. The means, shown in Table 8, support the suggestion that there is a disproportionately large cost to reading times when the first letter is substituted in preview, especially for the children.

Group	Orthographically dissimilar pseudohomophone previews	First fixation duration (ms)	Single fixation duration (ms)	Gaze duration (ms)
Adults	First letter manipulated	237 (78)	253 (78)	278 (85)
	First letter preserved	235 (76)	244 (77)	258 (80)
Children	First letter manipulated	312 (137)	339 (137)	379 (152)
	First letter preserved	301 (117)	320 (118)	346 (122)

Table 8

Mean and Standard Deviation (in parentheses) Reading Times on the Orthographically Dissimilar Pseudohomophone Previews

1.4 Discussion

The present study investigated parafoveal pre-processing of phonology, and the potential effects of orthography on this processing, in children and adults during silent English sentence reading. The results were quite clear and, in the main, supportive of the initial predictions. Firstly, the children's reading times on the target word were significantly longer than those of the adults. This demonstrates that the children experienced greater processing difficulty, that is, a slower rate of lexical processing, during reading than the adults, consistent with past research (e.g., Milledge et al., 2021). This has also been shown in simulations of the E-Z reader reflecting differences between adults' and children's eye movement behaviour during reading (Reichle et al., 2013). Secondly, the children, like the adults, were sensitive to manipulations of orthography in preview, consistent with past research (e.g., Balota et al., 1985; Johnson et al., 2018; Milledge et al., 2021; Pagán et al., 2016; Pollatsek et al., 1992). Thirdly, the adults did display evidence of a pseudohomophone advantage within the orthographically similar stimuli (albeit only significant in one measure, as discussed later). Critically, though, this study provides evidence that phonology also played a role in preview for 8- to 9-year-old readers of English; intact phonological codes present in preview facilitated lexical processing of word n+1. Interestingly, and in line with our predictions for the adults, there was evidence of an interactive effect between orthography and phonology and, with novelty, this was also found within the children: reading times were generally faster the greater the degree of orthographic similarity between the nonword previews and the correct target word, and, importantly, this effect was augmented for nonwords that maintained the target word's phonology in preview.

Clearly, the adults and the children were sensitive to manipulations of orthography in preview; both groups displayed preview benefit, that is longer reading times on a target word after a nonword preview compared to an identity preview (where no display change occurred). The children, like the adults, extracted orthographic information across the whole-word form in preview; when letter substitutions were present in preview this disrupted their processing, as shown by increased reading times, consistent with past research (e.g., Milledge et al., 2021; Pagán et al, 2016). It is potentially of note though that the present sample of children were at least "average" (Wechsler, 2005) readers for their age and were comparable to the adult readers with regard to pseudoword decoding, as it has been found that reading skill and decoding are greater predictors than age (school year) with regard to a child's ability to extract parafoveal information, that is, display preview benefit (Marx et al., 2016).

Critically, in two measures of very early processing, the children displayed a pseudohomophone advantage for the orthographically similar previews, and in one measure the adults showed this advantage too. Within the orthographically similar stimuli, when the phonology of the target word was maintained in preview, this facilitated children's (and adults') processing significantly, and to a significantly greater degree than was the case for a spelling control preview. The children clearly benefitted from correct phonological information being present in preview, and this facilitated lexical identification of the target, although orthographic similarity was evidently also playing a role. These results extend, and complement, existing research findings regarding children's, and adults', phonological and orthographic processing during silent sentence reading. Whilst such research has suggested that phonological processing is pre-lexical in child readers of English (Blythe et al., 2015; Jared et al., 2016), this study provides the first evidence of child readers extracting phonological information from an upcoming word through parafoveal pre-processing.

Importantly, as briefly mentioned previously, we found evidence of an interactive effect between phonology and orthography in preview. Whilst this replicates a known effect in adults and teenagers (Blythe et al., 2018, 2020; Pollatsek et al., 1992), this is novel for children. Interestingly, this indicates that the children were engaging in quite sophisticated parafoveal pre-processing, comparable to that of the skilled adult readers. The adult and beginner 8-year-old readers showed remarkable similarities in their parafoveal pre-processing: processing the same information from word *n*+1 that subsequently facilitated their lexical identification of that word during direct fixation. Indeed, the interaction found between phonology and orthography demonstrates that, for both adult and child readers, the ability to undertake phonological processing of word *n*+1 was modulated by orthographic similarity during early processing. The greater the overlap between the orthographic code(s) with the phonological code(s) of word *n*+1, potentially driven by the first letter, the greater the facilitation to lexical identification processes (consistent with Grainger & Ziegler, 2011). Parafoveal pre-processing would appear to be a skill that has, therefore, largely developed even in 8-year-old children to be similar to that of skilled adult readers, qualitatively; however, some quantitative differences remain, with children's reading and lexical identification processes being slower and less efficient than those of the adults. Presumably this continues to change developmentally, as beginner readers progress to be skilled readers and develop higher quality lexical representations (e.g., Perfetti, 2007).

The present experiment's findings are consistent with Grainger and Ziegler's (2011) model of orthographic processing, though we note again that the model is based on identification of directly fixated words presented in isolation and we are making inferences about how this might extend to parafoveal pre-processing during sentence reading. It is implicit within this model that there is a developmental change in lexical identification strategy from overt, effortful phonological decoding to the use of whole-word orthographic encoding (coarse-grained and fine-grained). Importantly, within this orthographic encoding, a mechanism is retained that allows phonological representations to be activated pre-lexically within the fine-grained route (phonological recoding; i.e., phonological information to be processed from word *n*+1). Consequently, both the adults (as would be expected) and the children appeared to be using the fine-grained route of processing: they were both able to rapidly, pre-lexically, extract phonological information from word *n*+1. As posited by this theory, though, orthography was also having an effect. Within the fine-grained route, as stated previously, there is little flexibility regarding orthographic encoding, and, as such, there is little tolerance for word misspellings. A pseudohomophone advantage was found, therefore, within the orthographically similar previews but not within the orthographically dissimilar previews: whilst word misspellings were present within both types of preview, within the orthographically similar previews the misspellings were clearly better tolerated, due to their lesser disruption to the orthographic processing the participants had to undertake (as only one letter was substituted in preview, never the first letter), in comparison to the orthographically dissimilar previews and their greater disruption to participants' orthographic processing (as at least two letters were substituted in preview, for half of the previews this involved at least the first letter). To be clear, we consider such effects might be a reflection of the importance of the first letter to both adult and child readers' parafoveal pre-processing, with its intact orthography facilitating the extraction of phonology from word *n*+1. Both orthographic and phonological codes appear to be extracted from preview and are used to integrate information across saccades (see Leinenger, 2014 for a review), supporting activation of the correct lexical candidate. As such, overlap (or consistency) between the phonological and orthographic codes available in preview facilitates the readers' lexical identification of word *n*+1, as found in the present research and consistent with past research (Blythe et al., 2018, 2020; Pollatsek et al., 1992). The first letter could potentially be especially important with regard to this overlap and the ease with which lexical identification can be achieved.

Indeed, the present study suggests that the adults and, especially the children, might have been displaying a first-letter bias in their parafoveal pre-processing, as shown previously by Milledge et al. (2021). Milledge et al. found, broadly consistent with past research (e.g., White et al., 2008), that the first letter played an important role in adults' pre-processing (the adults displayed longer reading times when the first letter was substituted in preview relative to the identity condition, where all letters were maintained in preview). In addition, Milledge et al. found that children, very early in their lexical processing (first fixation duration), displayed a first-letter bias: longer reading times after previews where the first letter was substituted relative to previews where the end letter was substituted). Within the present experiment, similarly, in first fixation and single fixation duration the children's reading times were more affected by the orthographic similarity of the nonword previews to the correct target word than those of the adults, with this effect being clearest for the orthographically dissimilar pseudohomophone previews. For example, within single fixation duration for the orthographically dissimilar previews, the children displayed, on average, longer reading times after a pseudohomophone preview compared to a spelling control preview. This could be due to the small number of observations within the present study, so some caution should be taken regarding the interpretation of these results. Importantly, though, within the orthographically dissimilar previews at least one of the letters being substituted would be the first and/or second letter (e.g., *kween* as a preview for *queen*), in contrast to the orthographically similar pseudohomophone previews where only one letter would be substituted, and it was never the first or second letter (e.g., *cheeze* as a preview for *cheese*). These substitutions of the first and/or second letters involved in the orthographically dissimilar pseudohomophone previews could have come at a particular cost to the children suggesting that, despite the correct phonological codes being present in preview, the children were not able to benefit from this information due to the letter substitutions occurring near the beginning of target words in preview. With half of the previews within the orthographically dissimilar pseudohomophone condition involving at least the first letter of the correct target word being substituted in preview, the increased disruption the children experienced to their reading times, very early in their processing (similar to Milledge et al., 2021), could potentially be attributable to this orthographic manipulation of the first letter/s in preview. Overall, given the interactive relationship found between orthography and phonology in both the adults and the children, the results suggest that the adults were similarly affected to the children: the greater the overlap between orthography and phonology, the more able readers were to benefit from phonological information in preview, with the first letter potentially playing a critical role in this overlap.

Like the children, the adults did experience benefits from correct phonological information being present in preview within the orthographically similar stimuli, broadly consistent with past research (e.g., Pollatsek et al., 1992). It is worth noting, however, that these benefits with regards to displaying a pseudohomophone advantage were mainly only present in numerical trends within our data. The pseudohomophone advantage was small in the adults and was not consistent across the early measures of processing (i.e., only significant in single fixation duration), unlike in the children. It is of note, though, that when looking at proportional increases within the orthographically similar stimuli, the mean costs between the pseudohomophone and spelling control previews were not that different between the adults and the children: first fixation duration, 6% for the adults, 9% for the children; single fixation duration, 7% for the adults, 10% for the children. This suggests that processing within the adults and the children was largely comparable, given the similar proportional increases. We consider that the small effect found within the adults in our formal analyses could be due to the stimuli used. Similar to Milledge et al. (2021) and Tiffin-Richards and Schroeder (2015), the stimuli used were designed to be suitable for the given age-group of child readers, not skilled adult readers. Consequently, the sentences would have been very easy for the skilled adults to read. This ease of processing may have resulted in the adults allocating more attention to processing of upcoming words within a sentence than they would have been able to do with more demanding, age-appropriate, sentences (e.g., Henderson & Ferreira, 1990; Rayner, 1986; though see also Zhang et al., 2019). As a result, smaller differences would have been found in reading times between the preview conditions. Thus, whilst the adults did display the predicted pattern of results numerically, significant effects were less likely to be found, given their greater ability (in comparison to the beginner child readers) to allocate more attentional resources towards pre-processing word *n*+1. Interestingly though, even in studies using stimuli designed for adult readers of English, the effect of phonology (pseudohomophones/homophones) in preview is typically small, about 4 ms in gaze duration, with little evidence of an effect of phonology in first fixation duration (Vasilev et al., 2019). The fact that we found a pseudohomophone advantage in the adult readers in an earlier measure of processing than gaze duration- single fixation duration-supports the notion that the stimuli, and the ease of the adults' processing, were potentially behind this effect. The adult readers seemed to be gaining an early advantage from phonology in preview (from orthographically similar previews), that is, before their eyes left a target word for the first time, but, by the time their eyes had moved onto the next word, they were no longer significantly displaying this effect.

Consistent with teenage readers (Blythe et al., 2018, 2020), the typically developing 8- to 9-year-old children were undertaking covert, rapid phonological recoding during their silent sentence reading. Although this has been suggested by past research investigating foveal processing (Blythe et al., 2015; Jared et al., 2016), this is the first experiment that has provided direct evidence of this through examining pre-lexical, parafoveal (pre-)processing. Clearly, typically developing 8- to 9-year-old beginner readers of English have made the transition from phonological decoding to recoding: they have moved beyond the slow, effortful sounding out of letters to identify a word to the rapid, pre-lexical processing of phonology, as demonstrated by their ability to lexically identify an upcoming word being facilitated by correct phonological information being present in preview (i.e., demonstrating pre-lexical processing). Whilst phonological decoding is a phase included in most theories of learning to read (e.g., Ehri, 1995, 1998, 1999, 2005, 2007; Marsh et al., 1981; Mason, 1980), what is unclear is exactly how, and when, beginner child readers make this transition from phonological decoding to recoding. Although the present experiment does not shed light on how exactly this transition occurs, the results do suggest that this transition has occurred at least by the time typically developing readers of English are 8-years-old. Future research could examine this issue. Given the ability to extract phonological information from the parafovea is dependent on the development of phonological recoding, due to the pre-lexical nature of this processing, it would be expected that younger child readers who have not made this transition would not show the same preview effects (i.e., they would not display a pseudohomophone advantage). In relation to Grainger and Ziegler's (2011) model, typical child readers of English, as young as 8-years-old, appear to have developed phonological processing, within their fine-grained route, that is comparable in efficiency to that of skilled adult readers: they can undertake rapid, covert, pre-lexical processing of phonology (phonological recoding). Younger child readers, however, who are reliant on the lexical, foveal strategy of phonological decoding should not be able to extract phonological information from an upcoming word, that is, display pre-lexical, parafoveal processing of phonology.

In sum, the current experiment provides novel evidence of 8- to 9-year-old beginner readers of English parafoveally pre-processing phonology, in a broadly similar way to skilled adult readers. Both groups displayed evidence of undertaking covert, pre-lexical phonological recoding. Of note also, though, is the key role orthography appears to play in facilitating this pre-processing of phonology.

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Appendix A

List of stimuli including the comprehension questions used (italicised underneath the relevant sentence)

Orthographically similar

Cheddar is my favourite kind of cheese/cheeze/cheene to have for lunch.

My sister got married in an old stone church/cherch/charch in Scotland.

We were taught to tie knots by our scout leader/leeder/leuder tonight.

We got our dog when she was a tiny puppy/puppi/puppa a long time ago.

Did we get our dog a long time ago?

The knight carried his sword and shield/sheeld/shueld when we went into battle.

Did the knight forget his sword?

Lisa wore trousers instead of her skirt/skert/skart when she went out.

Did Lisa wear her trousers?

We have a school holiday when it is hot in the summer/summur/summor which I love.

The curtains were closed behind the broken window/windoe/windou last night.

I am just 13 now so I will become 14 next year/yeer/yeor on my birthday.

The friendly dog sniffed me with his wet nose/noze/nove and it tickled.

Dad fought in a war because he was a soldier in the army/armi/armo years ago.

On the end of my new pencil is a pink rubber/rubbur/rubbir which I use a lot.

Is the rubber on my pencil yellow?

Orthographically dissimilar

Cows make milk and bees make honey/hunni/hanma which tastes nice.

Do bees make honey?

It is healthier to drink fruit juice/jooce/jeece than fizzy pop.

Is fizzy pop healthier than fruit juice?

I decided to buy some sweets with my pocket money/munni/menra this week.

People cheered for the king and queen/kween/treen as they waved from the window.

The chips were nice when I squeezed lots of brown sauce/sorce/sonce over them.

My uncle hit the golf ball/borl/bewl hard and it went right over the hill.

I used my mobile phone to make a quick call/kawl/tarl to my friend.

My dad sits in the car and beeps the horn/hawn/hemn when he is ready to go.

Does Dad beep the horn when he is ready?

I drew around a plate to make a perfect circle/sercle/norcle for my picture.

Did I draw around a mug to make a circle?

To make a pot, the artist used some wet clay/kley/bloy in his workshop.

Did the artist use clay for his pot?

Apple pips are in the middle bit, called the core/korr/borz, that you don’t eat.

The men lifted the car onto the lorry with a big crane/krain/drauv today.

Appendix B

Group	Condition	Single fixation probability
Adults	Identity	.75 (.50)
	Orthographically similar pseudohomophones	.77 (.49)
	Orthographically similar spelling controls	.76 (.62)
	Orthographically dissimilar pseudohomophones	.74 (.56)
	Orthographically dissimilar spelling controls	.76 (.64)
Children	Identity	.66 (.82)
	Orthographically similar pseudohomophones	.62 (.75)
	Orthographically similar spelling controls	.62 (.77)
	Orthographically dissimilar pseudohomophones	.66 (.86)
	Orthographically dissimilar spelling controls	.68 (.89)

Table B1

Single Fixation Probabilities and Standard Deviations (in parentheses) on the Target Word in Each Condition Across All Participants

Group	Condition	Percentage of skips
Adults	Identity	17.33% (.38)
	Orthographically similar pseudohomophones	7.34% (.26)
	Orthographically similar spelling controls	9.30% (.29)
	Orthographically dissimilar pseudohomophones	6.02% (.24)
	Orthographically dissimilar spelling controls	7.43% (.26)
Children	Identity	9.36% (.29)
	Orthographically similar pseudohomophones	9.32% (.29)
	Orthographically similar spelling controls	10.30% (.30)
	Orthographically dissimilar pseudohomophones	8.33% (.28)
	Orthographically dissimilar spelling controls	5.68% (.23)

Table B2

Skipping Rates and Standard Deviations (in parentheses) on the Target Word in Each Condition Across All Participants

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