The Importance of the First Letter in Children's Parafoveal Pre-processing in English: Is it Phonologically or Orthographically Driven?

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Word count: 9,110

Author Note

The data that supports the findings of this study, and the code used for the analyses, are available from https://osf.io/3jyqz/?view_only=6cbc981d5d144d03922a3a33e354fb08.

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Abstract

For both adult and child readers of English, the first letter of a word plays an important role in lexical identification. Using the boundary paradigm during silent sentence reading, we examined whether the first-letter bias in parafoveal pre-processing is phonologically or orthographically driven, and whether this differs between skilled adult and beginner child readers. Participants read sentences which contained either: a correctly spelled word in preview (identity; e.g., *circus*); a preview letter string which maintained the phonology, but manipulated the orthography of the first letter (P+ O- preview; e.g., *sircus*); or a preview letter string which manipulated both the phonology and the orthography of the first letter (P- O- preview; e.g., *wircus*). There was a cost associated with manipulating the first letter of the target words in preview, for both adults and children. Critically, during first-pass reading, both adult and child readers displayed similar reading times between P+ O- and P- O- previews. This shows that the first-letter bias is driven by orthographic encoding, and that the first letter's orthographic code in preview is crucial for efficient, early, processing of phonology.

Keywords: reading, parafoveal pre-processing, children, English, first-letter bias

Public significance statement:

It is known that encoding the first letter of a word is particularly important for a reader to accurately identify that word, but the reason for this has not previously been understood. We showed that the importance of the first letter of a word is based on the accurate encoding of its printed form (orthography), and is not due to the reader correctly encoding the letter's associated speech sounds (phonology). We showed that this is true for both skilled adult readers and beginner child readers of English.

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A word's orthography (its printed form) and phonology (its associated speech sounds) are inherently linked within alphabetic languages, though it is of note that this does vary based on orthographic depth and how consistent grapheme-to-phoneme correspondences (GPCs) are within a language (e.g., Katz & Frost, 1992). Nevertheless, within English, orthographic information visually represents the phonological codes of a word in order for word (lexical) identification to occur during reading. Past research has shown that the first letter of a word appears to play a vital role within both adults', and especially, children's lexical identification processes in English, facilitating lexical identification of an upcoming word (Milledge et al., 2020, 2021). It is unknown, however, exactly what drives this first-letter bias. In the present study, we examined the first-letter bias in 8- to 9-year-old readers of English, seeking to determine whether this bias might be phonologically or orthographically driven.

It is well-documented that, during silent reading, readers begin to process the upcoming word (*n*+1) in the sentence whilst still fixating the current word (*n*) (see Rayner, 1998, 2009 for reviews). This is referred to as parafoveal pre-processing, and leads to faster reading times for word *n*+1 when it is directly fixated due to the processing that has already occurred in relation to that word. Parafoveal pre-processing is enabled by the perceptual span (the area around the point of fixation from which readers can extract useful information), which is known to undergo developmental increases (e.g., Häikiö et al., 2009; Rayner, 1986; Sperlich et al., 2015, 2016), though it is also dependent on other factors like reading ability (e.g., Häikiö et al., 2009; Veldre & Andrews, 2014). Parafoveal pre-processing is typically studied using the boundary paradigm (Rayner, 1975). In this paradigm, an invisible boundary is placed immediately before a target word. Prior to the readers' eyes crossing this boundary, a preview letter string is present in place of the correct target word. When the readers' eyes cross this boundary, the preview letter string changes to the correct target word. Faster reading times on the target word following a correct preview (i.e., an identity condition, where the preview letter string is identical to the correct target word) compared to other preview letter strings (experimental conditions where the preview has been manipulated to be different in some manner) is known as preview benefit (see Schotter et al., 2012 for a review). Through systematic variation of the preview letter string in relation to the target word, researchers are able to determine the type of information readers extract and use from word *n*+1.

Past research using the boundary paradigm has shown that a word's external letters (both beginning and end) are particularly important to skilled adult readers' parafoveal pre-processing and subsequent lexical identification. Further, the first letter of a word plays a more privileged role than the end letter, during both parafoveal pre-processing and subsequent direct fixation (e.g., Briihl & Inhoff, 1995; Inhoff, 1987, 1989a,b; Johnson & Eisler, 2012; Johnson et al., 2007; Rayner et al., 1980; White et al., 2008). For example, White et al. (Experiment 1; 2008) found that reading times were slower when a word was present with external letter transpositions (e.g., *problme*, *rpoblem*) compared to internal letter transpositions (e.g., *porblem*, *probelm*). Within the external letter transposition conditions, however, reading times were slower when the transpositions occurred at the beginning relative to the end of a word (e.g., *rpoblem* vs. *problme*). The same pattern of effects was also observed when parafoveal pre-processing of the target word was prevented, through preview of the word to the right of fixation being unavailable (Experiment 2). This suggests that the first letter of a word plays a critical role in both parafoveal pre-processing and foveal lexical identification for skilled adult readers.

Similar effects have also been found within beginner child readers. Milledge et al. (2020) found that in children, like adults, the manipulation of external letters in preview was more detrimental to their lexical processing than the manipulation of internal letters in preview (e.g., *romter*, *sislun* vs. *somler*, *simlur* as previews for *sister*). Moreover, both adults and children experienced a clear cost when parafoveal pre-processing of the first letter was denied. This first-letter bias occurred earlier during lexical processing for children than was the case for effects of other letter manipulations. For the majority of effects reported, the time course was delayed in children compared to adults (e.g., not present in first fixation duration but present in gaze duration and total reading time). In contrast, when the first letter was substituted in preview, both the adults' and the children's parafoveal pre-processing was immediately, and similarly, disrupted. Evidently, the beginning letter of a word plays an important role in facilitating both children's and adults' lexical identification of word *n*+1, given the cost to their reading times when this letter is disrupted in preview.

This first-letter bias is a robust finding within the literature, but it is unclear as to what causes it. Within skilled adult readers, the possibility that this effect occurs due to fundamental constraints of the visual system, like visual acuity and lateral masking, can be rejected. For example, Johnson and Eisler (2012) found that when lateral masking was equated for all letters of a word through the replacement of inter-word spaces with #s (e.g., The#boy#could#not#solve#the#problem#so#he#asked#for#help.), word initial letter transpositions still caused more disruption to reading than word final transpositions, whilst the end letter transpositions were no more disruptive than internal letter transpositions (Experiments 1 and 2). Furthermore, manipulations of the first letter of a word remain particularly disruptive even when participants are required to read sentences backwards, from right to left (e.g., *.help for asked he so problem the solve not could boy The*) (Experiment 4; Johnson & Eisler, 2012). Within such sentences, during fixation on word *n* (e.g., *the*), the first letter of word *n*+1 (e.g., the *p* in *problem*) falls furthest away from the point of fixation. The first letter of the word being pre-processed will, therefore, be perceived with the lowest visual acuity within that word, whilst the final letter (e.g., the *m* in *problem*) will be perceived with the highest visual acuity, as it falls closest to the point of fixation on word *n*. Even under such conditions, manipulations of the first letter in preview (e.g., *rpoblem*) were more disruptive to reading than manipulations of the last letter in preview (e.g., *problme*). Consequently, visual factors, like lateral masking and the proximity of the first letter to the point of fixation (visual acuity), do not seem to play a causal role in the importance of the first letter to lexical identification. This suggests that the first-letter bias may be driven by cognitive processing associated with lexical identification. However, this leads to the question of whether the parafoveal pre-processing that operates over the word initial letters is associated with the extraction of orthographic or phonological information.

First, it could be occurring as part of orthographic encoding, given the effect orthographic manipulations of the first letter have on both adults' and children's ability to lexically identify a word (e.g., Milledge et al., 2020). Alternatively, the effect could be caused by the reader's generation of a phonological code, which necessarily requires left-to-right processing of the letters within a word. Skilled adult readers pre-process phonological codes from word *n*+1 as part of lexical identification in silent sentence reading, as shown in a number of studies that have used the boundary paradigm. For example, adults display faster reading times after a homophone preview (e.g., *beech* as a preview for *beach*) compared to a spelling control preview (e.g., *bench* as a preview for *beach*; Chace et al., 2005; Pollatsek et al., 1992). Similarly, it has been found that beginner child readers also extract phonological information from word *n*+1; for example, through displaying faster reading times on a target word after a pseudohomophone preview (e.g., *cheeze* as a preview for *cheese*) compared to a spelling control preview (e.g., *cheene* as a preview for *cheese*) (Milledge et al., 2021). It is possible, therefore, that the first-letter bias could be phonologically driven in adult and child readers.

The first-letter bias has been accounted for by various models of word recognition, though we note that these models typically relate to isolated word recognition under direct fixation, not during parafoveal pre-processing (e.g., Davis, 2010; Grainger & Ziegler, 2011; Perry et al., 2007; Whitney, 2001). For example, the SERIOL (Whitney, 2001) and Spatial Coding (Davis, 2010) models of visual word recognition both account for this importance of the first letter: within the SERIOL model, given left-to-right scanning of a word, letters in the first position receive the most activation; within the Spatial Coding model, dynamic end-letter marking is used, such that the first and final letters of a word are weighted more heavily than other constituent letters of a word. Both models, therefore, predict that the first letter plays a vital role in lexical identification. Moreover, given these models relate to letter position encoding (an orthographic effect), not only do they predict the importance of the role of the first letter to lexical identification, but that this role is, first and foremost, orthographically driven.

Despite the models' focus upon isolated word recognition, they do have the potential to provide insight into lexical identification processes, regarding word *n*+1, during natural sentence reading (e.g., Pagán et al., 2016). Consequently, insight can be gained from such models into why the first-letter bias occurs and what may drive this effect. For example, Grainger and Ziegler's (2011) model of word recognition proposes that there are two processing routes through which lexical identification can be achieved: coarse-grained and fine-grained. The coarse-grained processing route gives a reader access to semantics (meaning) from a word's orthographic form. The fine-grained route, in contrast, provides a reader access to semantics through the processing and mapping of commonly occurring letter patterns onto their corresponding phonological representations. Whilst the former route allows some flexibility with regard to orthographic encoding, the latter route allows little flexibility with regard to orthographic encoding (i.e., reduced tolerance of word misspellings). Specifically, it would appear that the first letter's correct orthographic code plays a particularly important role within the orthographic encoding readers undertake in the fine-grained route to lexically identify a word, facilitating efficient processing of phonology, potentially due to serial letter processing (e.g., Kwantes & Mewhort, 1999; Whitney, 2001) and the first letter constraining the number of possible lexical candidates (e.g., Clark & O'Regan, 1999; Grainger & Jacobs, 1993). For example, Milledge et al. (2021) found that both adults and children only displayed a pseudohomophone advantage when the first letter was not substituted in preview (orthographically similar stimuli; e.g., *cheeze* vs. *cheene* as previews for *cheese*). In contrast, no pseudohomophone advantage was found within the orthographically dissimilar stimuli (half of these previews involved the substitution of the first letter; e.g., *kween* vs. *treen* as previews for *queen*). To be clear, given the supposition that phonological lexical representations are accessed via encoding and recognition of corresponding orthographic form/s (Perry et al., 2007), the first letter of a word may be crucial for readers to translate an orthographic code into a phonological code. This would suggest that the first-letter bias is potentially, primarily, orthographically driven, rather than phonologically driven.

In the present study, we examined whether the first-letter bias in parafoveal pre-processing is orthographically or phonologically driven by manipulating the features of the first letter of target words in parafoveal preview. We compared the effects of these manipulations, and their time course, for beginning and skilled adult readers. Previews were either: the correct target word (identity; e.g., *circle*); a letter string with the first letter substituted such that the phonological code of the first letter was maintained (P+ O-; e.g., *sircle*), or a letter string with the first letter substituted such that both the phonological and orthographic codes were disrupted (P- O-; e.g., *nircle*).

First, we predicted that both children and adults would show a cost to their processing when the first letter was substituted in preview, compared to the identity condition (Milledge et al., 2020, 2021).[1] Second, we predicted that a comparison of the two substitution conditions would indicate the cause of the first-letter bias. Specifically, if the effect is phonologically based, then we would expect shorter reading times after a preview where the phonological code of the first letter was preserved (e.g., faster reading times on a target word after a P+ O- preview compared to a P- O- preview). Alternatively, if the first-letter bias is orthographically driven then we would expect both substitution conditions to have similar reading times. We also predicted that overall group differences would be found (i.e., the children would display longer reading times than the adults), as age-related changes in eye movement behaviour are well-documented. Typically, as chronological age increases, fixation durations decrease (e.g., Blythe et al., 2009, 2011; Huestegge et al., 2009; Joseph et al., 2009; Vorstius et al., 2014). In addition, we predicted that differences in the time course of effects were likely to be found between the adults and the children. In particular, we predicted delays in the children's parafoveal pre-processing of orthography compared to that of the adults (i.e., the children to be less affected than the adults by P- O- previews in comparison to the identity condition within early measures of processing, but to pattern more consistently with the adults within later measures of processing; Milledge et al., 2020).

Method

Participants

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[1] Although adult readers do not necessarily show a traditional first-letter bias in their pre-processing where stimuli designed for children are used, they do still seem to use the first letter as an important cue within their pre-processing (Milledge et al., 2020).

Forty-two adults (*M* = 22.17, *SD* = 3.15) and 42 8- to 9-year-old (*M* = 8.43, *SD* = .50) children from a local junior school participated in the eye-tracking experiment (see Table 1 for a summary of group characteristics). All were native speakers of English, had normal or corrected to normal vision, and no known reading difficulties, as confirmed by the Wechsler Individual Achievement Test II UK (WIAT-II UK; Wechsler, 2005) reading subtests. All participants' composite standardised scores were within the expected range (adults' score range: 92-134; children's score range: 95-142; see also Table 1). Ethical approval was provided by the University of Southampton Psychology Ethics Committee (submission ID: 52927.A1).

Table 1

Summary of Group Characteristics

		Mean	StDev	*t*	*df*	*p*
Test age (years)	Adults	22.17	3.15			
	Children	8.43	.50	27.88	82	< .001
WIAT word reading	Adults	111.60	4.57			
	Children	111.86	10.37	-.15	82	.881
WIAT pseudoword decoding	Adults	107.14	8.86			
	Children	107.17	8.00	-.01	82	.990
WIAT comprehension	Adults	113.81	5.63			
	Children	115.07	7.70	-.86	82	.394
WIAT composite standardised scores	Adults	115.10	9.06			
	Children	112.90	11.44	.97	82	.334

Note. The three right-hand columns give the results of independent samples *t*-tests comparing the adults to the children. All WIAT scores are standardised.

Materials and Design

We selected 24 potential 5-7 letter target words, which were either nouns or adjectives. These target words were selected on the basis that the first letter of each of the words could be substituted with an orthographically similar letter (e.g., a descender replaced with a descender), in order to create a preview letter string that would maintain the phonology of the target word (e.g., a pseudohomophone). This was done due to the interactive relationship between orthography and phonology (Milledge et al., 2021); specifically, the orthographic dissimilarity of the first letter in preview (e.g., *c* substituted with *k*; *kley* as a preview for *clay*) could play a role in further disrupting readers' ability to extract phonological information from word *n*+1, given how orthography has been found to be pre-processed by children (e.g., Johnson et al., 2018; Pagán et al., 2016). Consequently, and given the constraints within the English language, all target words either began with a *c* that could be substituted with a *s* in preview to give the first letter its correct phonological code (e.g., *sircle* as a preview for *circle*) or a *g* that could be substituted with a *j* in preview (e.g., *jiraffe* as a preview for *giraffe*).

For each of the 24 target words, four potential sentence frames were created. All materials were pre-screened for both the difficulty of the sentences and whether the given target words were known and recognised by the target age group. Forty-five 8- to 9-year-old children (all of whom were native speakers of English with no known reading difficulties, and none of whom took part in the eye-tracking experiment) rated the sentences on a scale of 1 (easy to understand) to 7 (difficult to understand). The children were also asked to underline any words in the sentences that they did not know or recognise. The target words and sentence frames were selected to ensure that they were easy for our target age group to understand (had a mean rating under 2.00) and on the basis of the target words being known by all of the children. As a result of this pre-screening, seven target words and their associated sentence frames were dropped. This left a final stimulus set of 17 target words (the linguistic properties of these words are shown in Table 2). For each of these target words, three sentence frames were chosen for the eye-tracking experiment; the sentence rated as most difficult, on average, out of the four potential sentence frames was dropped. Consequently, the final stimulus set consisted of 51 experimental sentences (see Appendix A).

Table 2

Linguistic Properties of the Target Words and Sentence Frames

	Target words		
	Range	*M*	*SD*
Orthographic neighbours (N-Watch; Davis, 2005)	0-2	.41	.62
Age of Acquisition (Kuperman et al., 2012)	3.67-8.85 years	6.28	1.56
Child frequency counts (Children's Printed Word Database; Masterson et al., 2003)	3-430 per million	55	103
Adult frequency counts (English Lexicon Project Database; HAL corpus, Balota et al., 2007)	379-148,204 per million	26,531	38,810
Understandability (1 *easy* to 7 *difficult*)	1-1.53	1.17	.57

Note. The adult frequency counts refer to 16 of the target words (*gerbil* was not available in the database).

The gaze-contingent boundary paradigm (Rayner, 1975) was used. In the present experiment, three parafoveal preview conditions were generated for each target word. There was an identity (control) condition, where the preview letter string was identical to the correct target word (e.g., *giraffe - giraffe*), and two experimental conditions, which involved the substitution of the first letter of each of the target words in preview: P+ O- previews (where the correct phonological code of the first letter was maintained in preview and orthography was manipulated; e.g., *jiraffe - giraffe*) and P- O- previews (where both the phonological and orthographic codes of the first letter were manipulated in preview; e.g., *piraffe - giraffe*). All nonwords were orthographically legal and pronounceable. The P+ O- and P- O- previews were matched on bigram and trigram frequency, as well as orthographic neighbourhood size (the number of real words that could be formed by making a single, position-specific letter substitution), *t*s < .59 (N-Watch; Davis, 2005).

Every participant read all of the 51 experimental sentences, contributing data to all conditions, and 17 filler sentences were also included. As every participant saw each target word three times, and was provided with three different previews, within the 51 experimental sentences the preview condition presentation order was carefully controlled: six files were created accounting for each possible combination of preview presentation (i.e., whether a given participant had an identity preview of a given target word on first, second, or third presentation, or a P+ O- preview, or a P- O- preview). The order of the items within each file was also carefully controlled and fixed, such that only the type of preview changed. This meant that the items were equidistant (and their three presentations were maximally distanced from each other) within each file. The sentences occupied one line on the screen (maximum = 55 characters; *M* = 50 characters; e.g., *Ben enjoyed seeing the tall giraffe at the zoo.*).

Apparatus and Procedure

An EyeLink 1000 eye-tracker recorded eye movements of the right eye (SR Research). Forehead-and-chin rests were utilised to minimise head movements. A three-point calibration and validation procedure was carried out. The procedure would be repeated if the mean validation error, or the error for any of the individual points, was greater than .2°. A single sentence was presented to participants at a time in black, Courier New, 14-point font on the grey background of a 21in. CRT monitor, which had a refresh rate of 120 Hz. The viewing distance was 60 cm; one character subtended .34° of visual angle. Participants were instructed to read silently and for comprehension. In order to familiarise participants with the procedure, they were presented with four practice trials at the beginning of the experiment (with two comprehension questions). After finishing reading a sentence, participants would press a response key, and one third of the sentences were replaced by a yes/no comprehension question to which the participants would have to respond. After the eye-tracking, participants were asked if they had noticed anything strange about the sentences they had been reading, as detecting display changes can affect fixation times (e.g., White et al., 2005). Even if a participant reported they noticed something strange about only one sentence (be it flickering or noticing a word change), their data was excluded. Six adult participants' data was excluded from the analyses on this basis and were replaced with adult datasets where no display changes were detected. Participants then completed the three reading subtests of the WIAT-II UK (Wechsler, 2005). The whole experiment lasted about 50 minutes per participant.

Power Analysis

We conducted a power analysis using the PANGEA software (https://jakewestfall.shinyapps.io/pangea/; Westfall, 2015), specifying a 2 (group) × 3 (condition) mixed design. Firstly, we examined the power of the main effect of condition; specifically, we compared a nonword preview condition (P+ O-/P- O-) to the identity condition within the adult participants (as they would form our reference group). We assumed an effect size of *d* = .40, given the well-established cost associated with manipulations that involve the first letter in preview for adult readers (e.g., Johnson et al., 2007; Milledge et al., 2020; Pagán et al., 2016).[2] Our experiment did have sufficient power to detect preview benefit with 34 stimuli (e.g., comparing P- O- previews to the identity condition) and 42 participants per group, using the recommended minimum power value of .80 (Cohen, 1962); our power value was .86.

Regarding our ability to detect an effect of phonology, comparing P+ O- previews to P- O- previews, an estimate of effect size was very difficult to determine due to the exact nature of our experimental manipulation. The vast majority of past research that has examined parafoveal pre-processing of phonology has not involved the manipulation of the first letter in preview, and the studies that have (e.g., Blythe et al., 2018, 2020; Milledge et al., 2021; Pollatsek et al., 1992) manipulated more than the first letter in preview. Given, though, the cost (as demonstrated and discussed above) to lexical identification caused by manipulations that involve the first letter in preview, if any benefit to lexical identification can be gained from phonology, this effect would be expected to be larger than what is typically seen within research examining parafoveal pre-processing of phonology (see Vasilev et al., 2019), especially given that only orthographically similar letter substitutions were made (e.g., Johnson et al., 2018; Milledge et al., 2021; Pagán et al., 2016).

Secondly, we examined the power of the interaction between group and condition. Specifically, we predicted that the children would be less affected than the adults by P- O- previews in comparison to the identity condition within early measures of processing (e.g., first fixation duration). We note that no previous research has examined the role that, solely, the first letter plays in preview for adults and children (i.e., it is the case that other letters have always also been manipulated in preview). Milledge et al. (2020), though, did find

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[2] Milledge et al. (2020) found, on average, a 35 ms cost in first fixation duration and a 48 ms cost in gaze duration when comparing a condition where the first letter had been substituted in preview to the identity condition; (*d* = .45 and *d* = .48, respectively). Johnson et al. (2007) found similar costs (36 ms in first fixation duration and 51 ms in gaze duration; SL, initial condition vs. identity condition). Pagán et al. (2016) found an effect size of *d* = .36 (29 ms cost) in first fixation duration and *d* = .35 (38 ms cost) in gaze duration (SL13 condition vs. identity condition).

evidence of children’s parafoveal pre-processing of orthography being slower than that of adults (comparing nonword previews to identity previews; Model 1). We calculated an estimate of effect size for the interaction term ‘Children × 1ddd56’ (e.g., *machey* as a preview for *monkey*) for first fixation duration, which produced an estimate of *d* = .28. Within the present experiment, using PANGEA (Westfall, 2015) to examine the power of the interaction ‘Children × P- O-’ using *d* = .28, our power value was .76. Note, however, that both adults’ and children’s lexical identification is disrupted when a manipulation involves the first letter of a word in preview (in first fixation duration, adults- 35 ms cost; children- 30 ms cost). As such, we consider that an estimated interaction effect size of *d* = .30 would be a more reasonable (yet still conservative) estimate; using such an effect size produced a power estimate of .81. We were confident, therefore, that if there were any interactive effects, our present experiment would have sufficient power to determine this. Any non-significant interactions would, of course, be treated with caution and Bayesian analyses would be conducted to allow for rigorous evaluation.

Results

All participants scored at least 76% on the comprehension questions (adults: *M* = 98.32%, *SD* = 2.99%; children: *M* = 93.84%, *SD* = 7.11%). The data were trimmed using the clean function in DataViewer (SR Research). Fixations shorter than 80 ms, and which were located within one character space of a neighbouring fixation, were merged into the neighbouring fixation. Remaining fixations that were shorter than 80 ms or longer than 1,200 ms were deleted. In total 1,370 fixations were merged or deleted (2.25% of the dataset; 637 adult fixations and 733 child fixations), resulting in a final dataset of 59,509 fixations.

All 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). Participants and items were entered as crossed random effects. For each model, full random structures were initially specified for items and participants, to avoid being anti-conservative (Barr et al., 2013). Failure of the models to converge for each dependent measure led to the models' structures being trimmed until they would converge. Data (for both global and local analyses) were log transformed before analysis to reduce skew.[3]

Global Measures

Firstly, we examined global measures of participants' eye movement behaviour (eye movements across entire sentences). As can be seen in Table 3, the children displayed significantly longer fixation durations ($b = .10$, $SE = .02$, $t = 4.61$, $p < .001$), longer total sentence reading times ($b = .53$, $SE = .07$, $t = 7.31$, $p < .001$), and made more fixations ($b = .39$, $SE = .05$, $z = 7.20$, $p < .001$) than the adults, consistent with previous research (e.g., Blythe et al., 2011; Blythe & Joseph, 2011; Joseph et al., 2009; Tiffin-Richards & Schroeder, 2015).[4]

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[3] Note that, within the global analyses, due to the nature of the fixation count data it was not log transformed and was analysed using a generalized linear mixed model, in order to use the Poisson distribution.

[4] Following trimming, the syntax for fixation count was: *Fix_count ~ Group + (1|Participant) + (1 + Group|SentenceNo)*, the syntax for total sentence reading time was: *Total_sentence_reading ~ Group + (1|Participant) + (1 + Group|SentenceNo)*, and the syntax for fixation duration, as an intercepts only model, was: *Fix_duration ~ Group + (1|Participant) + (1|SentenceNo)*.

Table 3

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

Measure	Adults	Children
Fixation duration (ms)	239 (116)	273 (150)
Fixation count	11 (4)	17 (6)
Total sentence reading time (ms)	2624 (1141)	4635 (2413)

Local Measures

Subsequently, we analysed reading time data on the target word in each sentence. Before analysing the local dependent measures, the data were further cleaned: trials were excluded from the analyses if the boundary change occurred early during a fixation on the pre-target word and if the boundary change was late- not completed until more than 15 ms after fixation onset on the target word (224 adult trials- 10.46% of the adult trials, and 202 child trials- 9.43% of the child trials).[5]

The key dependent measures were: first fixation duration (the duration of the first fixation on a word, irrespective of how many fixations the word received), single fixation duration (the duration of the first fixation on the word when it received only one first-pass

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[5] A late boundary change was also operationalised as 10 ms, in order to ensure that the pattern of data remained consistent across the two reports. The pattern of data was highly consistent across the 15 ms and 10 ms reports, across all measures, so the 15 ms criterion of a late boundary change was used as it retained more data (3,858 data points compared to 3,672). After the boundary change cleaning, regarding the total number of items recorded for each participant, within the adults the lowest total number of items recorded was 35 (*M* = 45.67, total range: 35-51; identity *M* = 15.05, range: 9-17; P+ O- *M* = 15.69, range: 12-17; P- O- *M* = 14.93, range: 11-17) and within the children this was also 35 (*M* = 46.19, total range: 35-51; identity *M* = 15.57, range: 11-17; P+ O- *M* = 15.05, range: 11-17; P- O- *M* = 15.57, range: 11-17).

fixation), gaze duration (the sum of all first-pass fixations on a word before the eyes move from that word), selective regression path duration (the sum of all fixations made from the moment the eyes land on a target word until the first fixation to the right of the target word, not including time spent rereading preceding text), and total reading time (the sum of all fixations made on a target word); see Table 4.[6]

Table 4

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

Group	Condition	First fixation duration (ms)	Single fixation duration (ms)	Gaze duration (ms)	Selective regression path duration (ms)	Total reading time (ms)
Adults	Identity	211 (71)	212 (71)	239 (101)	261 (128)	356 (261)
	P+ O-	228 (80)	237 (81)	264 (100)	284 (117)	387 (246)
	P- O-	233 (76)	241 (78)	275 (116)	301 (130)	387 (229)
Children	Identity	273 (120)	283 (116)	410 (298)	498 (353)	682 (597)
	P+ O-	292 (140)	307 (132)	434 (303)	512 (359)	665 (504)
	P- O-	279 (134)	300 (135)	447 (324)	539 (352)	727 (541)

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[6] The probability of the children making a single fixation across all trials was .56 and the probability of the adults making a single fixation across all trials was .77. 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. The only significant finding from the generalized linear mixed models conducted for this measure was that, within Model 1 (intercepts only model), the adults were significantly less likely to skip a P- O- preview than an identity preview (p = .011), and the lack of significant interaction term suggests that the children’s skipping behaviour was consistent with that of the adults (p = .262).

Two lme models were run for each dependent measure. Model 1 compared the letter substitution previews (P+ O-, P- O-) to the identity condition, with participant group included as an interaction term. This allowed us to examine the potential costs associated with a nonword preview, examining whether the participants displayed preview benefit, with the adults acting as the baseline. Then custom contrasts (second lme model) were specified to directly compare the letter substitution preview conditions, in order to determine whether phonology might play a role in the first-letter bias. Effects were considered significant when $|t| > 1.96$.

As word length varied (stimuli word length ranged between 5-7 letters), lme models were also run with length as a factor. For all of the dependent measures, word length had no significant effect (intercepts only models; $|t| < 1.54$). Formal model comparisons were also conducted to examine word length’s role within our data. The comparisons showed, again within all dependent measures, that including word length did not improve the fit of our models and contrasts, *p*s > .242, thus, we report the results from the models that do not include word length for the sake of brevity and simplicity. In addition, given that each participant was presented with three different previews of each target word (six files accounted for every combination possible), formal model comparisons were conducted to determine whether preview presentation order might have had an effect on participants’ processing (reading times would be expected to decrease on any given target word over the second and third presentations of that target, akin to a practice effect). The comparisons showed that for first fixation duration, single fixation duration, and gaze duration, the inclusion of presentation did not improve the fit of our models and contrasts, *p*s > .104. Within selective regression path duration and total reading time, however, presentation did improve model fit when included as a main effect (additive) term, *p*s < .001.[7] The effect of presentation is considered and summarised here, as the findings are not pertinent to the interpretation of our experimental manipulations: reading times were significantly faster after the second and third time a target word was presented to participants, relative to the first time (as shown in the model and contrast results reported below- see also Appendix B; Figure B1), but reading times were not significantly different between the second and third times that participants saw each target word (see Appendix B; Table B3 and Figure B1).

To reiterate, Model 1 used the identity condition as a baseline, with each of the substituted letter preview conditions (P+ O-, P- O-) compared to it, and with the children's data compared to the adult data (i.e., the intercept corresponded to the average reading times of the adults for the identity condition, and for presentation 1 within the later reading time measures). The results of this model, for each dependent measure, are shown in Tables 5 (first fixation duration, single fixation duration, and gaze duration) and 6 (selective regression path duration and total reading time; note that the models for these measures also include presentation order). The contrasts directly compared the P+ O- previews to the P- O- previews, in order to examine the effect the first letter's phonological code being maintained in preview had on both adults' and children's parafoveal pre-processing (i.e., it could be determined whether the first letter's phonology being preserved in preview facilitated lexical identification compared to when it was disrupted in preview). Contrasts for the previews were specified as 1/-1, such that the intercept corresponded to the grand mean and the contrast represented the difference between the two conditions.

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[7] Given the inclusion of presentation as an additive term (vs. no term) significantly improved model fit within these measures, we also ran model comparisons comparing its inclusion as an additive term against its inclusion as an interactive term. The models with presentation included as an additive term were a better fit than the models with presentation included as an interactive term, *p*s > .278.

Table 5

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

	First fixation duration				Single fixation duration				Gaze duration			
	b	SE	*t*	*p*	b	SE	*t*	*p*	b	SE	*t*	*p*
Adults, Identity (Int)	5.30	.02	217.87	< .001	5.31	.03	189.11	< .001	5.40	.04	133.90	< .001
Group (Adults vs. Children)	**.23**	**.03**	**7.16**	**< .001**	**.28**	**.04**	**7.25**	**< .001**	**.45**	**.05**	**8.43**	**< .001**
Adults, P+ O-	**.08**	**.02**	**3.09**	**.003**	**.11**	**.02**	**5.11**	**< .001**	**.11**	**.02**	**4.57**	**< .001**
Adults, P- O-	**.10**	**.02**	**4.70**	**< .001**	**.13**	**.02**	**6.01**	**< .001**	**.14**	**.02**	**6.02**	**< .001**
Children × P+ O-	-.03	.03	-.72	.471	-.04	.03	-1.28	.199	-.04	.03	-1.25	.210
Children × P- O-	**-.10**	**.03**	**-3.29**	**.002**	**-.09**	**.03**	**-2.86**	**.004**	**-.07**	**.03**	**-2.14**	**.032**
Contrasts												
Intercept (grand mean)	5.45	.02	271.16	< .001	5.50	.02	236.10	< .001	5.69	.04	157.41	< .001
Adults, P+ O- vs. P- O-	-.02	.02	-1.06	.288	-.02	.02	-.89	.372	-.03	.02	-1.46	.146
Children, P+ O- vs. P- O-	**.05**	**.02**	**2.47**	**.014**	.03	.03	1.32	.188	-.01	.02	-.28	.778

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. Following trimming, the syntax for first fixation duration was: *depvar ~ Group * condition + (1 + condition|Participant) +*

(1|targetno), and for single fixation duration and gaze duration the syntax, as intercepts only models, was: *depvar* ~ *Group* * *condition* + *(1|Participant)* + *(1|targetno)*. Within the contrasts, after trimming, the syntax for all measures, as intercepts only models, was: *depvar* ~ *GroupByCond* + *(1|Participant)* + *(1|targetno)*.

Table 6

Output from Model 1 and the Contrasts for Selective Regression Path Duration and Total Reading Time

	Selective regression path duration				Total reading time			
	b	SE	*t*	*p*	b	SE	*t*	*p*
Adults, Identity, Presentation 1 (Int)	5.54	.05	111.63	< .001	5.80	.06	101.84	< .001
Group (Adults vs. Children)	**.58**	**.06**	**9.03**	**< .001**	**.60**	**.07**	**8.21**	**< .001**
Adults, P+ O-	**.10**	**.03**	**3.88**	**< .001**	**.11**	**.03**	**4.16**	**< .001**
Adults, P- O-	**.16**	**.02**	**6.54**	**< .001**	**.13**	**.03**	**4.82**	**< .001**
Adults, Presentation 2	**-.11**	**.02**	**-6.35**	**< .001**	**-.16**	**.02**	**-8.21**	**< .001**
Adults, Presentation 3	**-.11**	**.02**	**-6.03**	**< .001**	**-.16**	**.02**	**-8.15**	**< .001**
Children × P+ O-	-.07	.04	-1.78	.079	**-.11**	**.04**	**-2.75**	**.006**
Children × P- O-	**-.07**	**.03**	**-2.12**	**.037**	-.05	.04	-1.20	.230
Contrasts								
Intercept (grand mean), Presentation 1	5.90	.04	131.52	< .001	6.15	.05	119.46	< .001
Adults, P+ O- vs. P- O-	**-.06**	**.02**	**-2.58**	**.010**	-.02	.03	-.66	.508
Children, P+ O- vs. P- O-	**-.05**	**.02**	**-2.33**	**.020**	**-.08**	**.03**	**-2.94**	**.003**

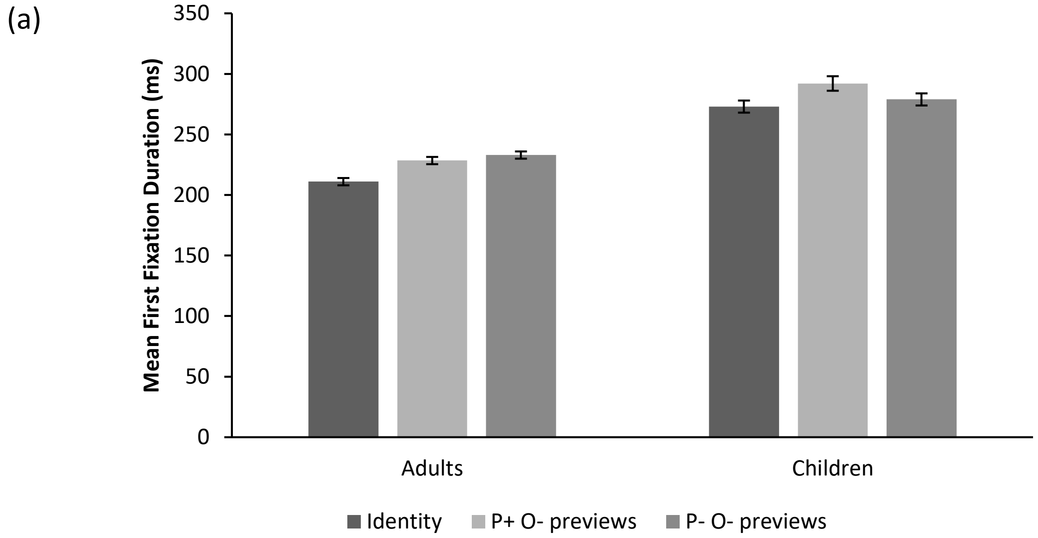
Presentation 2	**-.12**	**.02**	**-7.51**	**< .001**	**-.16**	**.02**	**-8.17**	**< .001**
Presentation 3	**-.11**	**.02**	**-6.88**	**< .001**	**-.16**	**.02**	**-8.15**	**< .001**

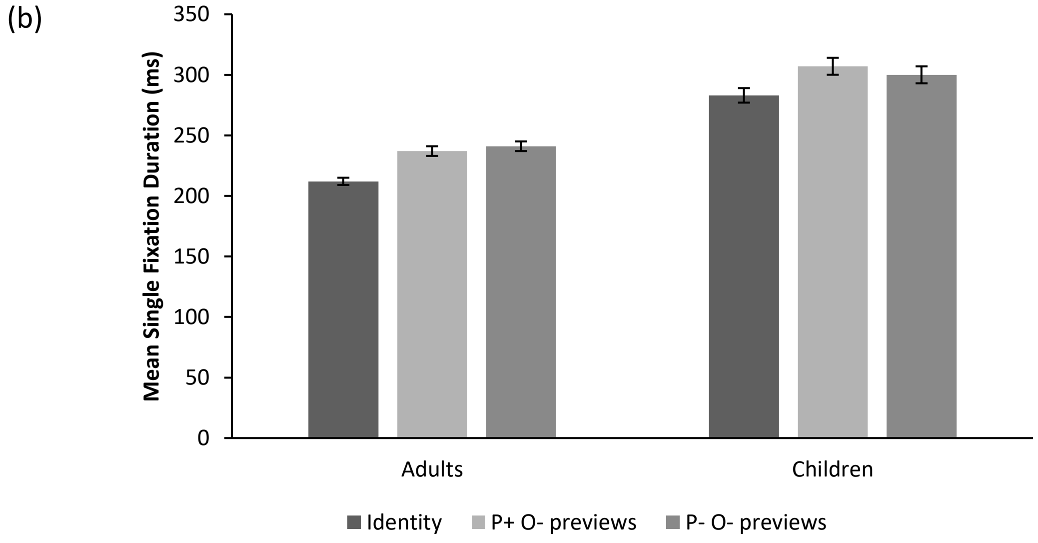
Note. The reading time data were log transformed prior to analysis, so the model estimates cannot be directly interpreted. Significant effects are marked in bold. Following trimming, the syntax for selective regression path duration was: *depvar ~ Group * condition + presentation + (1 + condition|Participant) + (1|targetno)*, and the syntax for total reading time, as an intercepts only model, was: *depvar ~ Group * condition + presentation + (1|Participant) + (1|targetno)*. Within the contrasts, after trimming, the syntax for both measures, as intercepts only models, was: *depvar ~ GroupByCond + presentation + (1|Participant) + (1|targetno)*.

Firstly, within all measures, there were significant group differences: the children displayed significantly longer reading times than the adults (see Tables 4, 5, and 6, and Figure 1). Second, across all measures, the adults displayed clear preview benefit such that both substituted letter previews resulted in longer reading times than the identity preview.

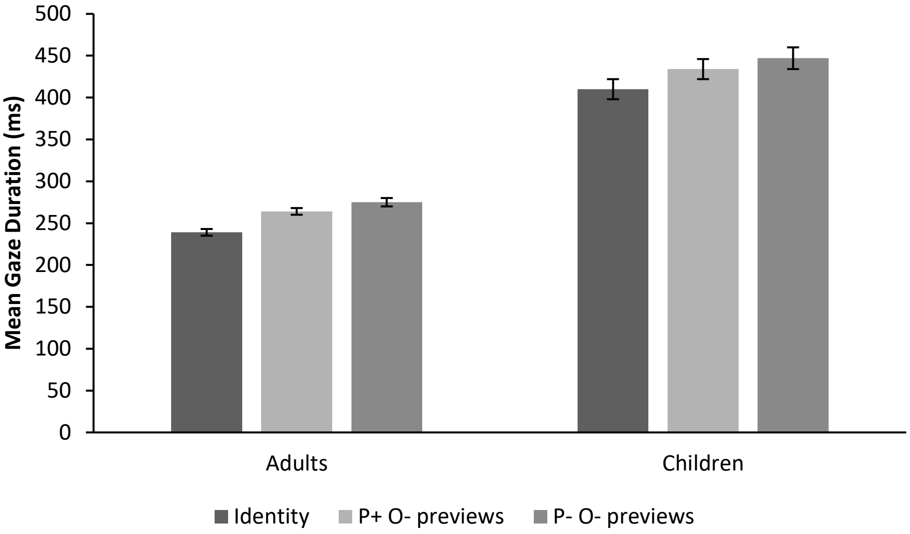
Figure 1

Mean First Fixation Durations (a), Single Fixation Durations (b), Gaze Durations (c), Selective Regression Path Durations (d), and Total Reading Times (e) on Identity, P+ O- Previews, and P- O- Previews for Both Adults and Children

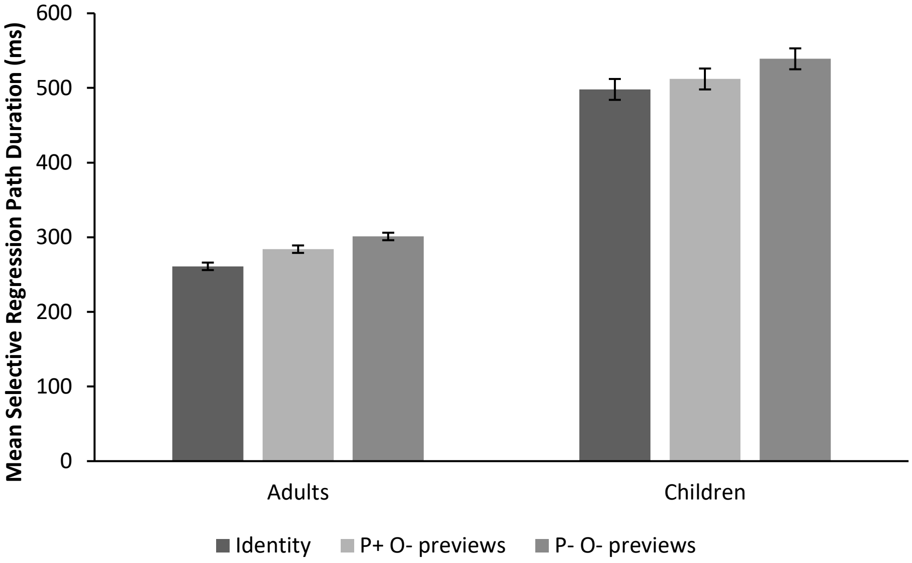




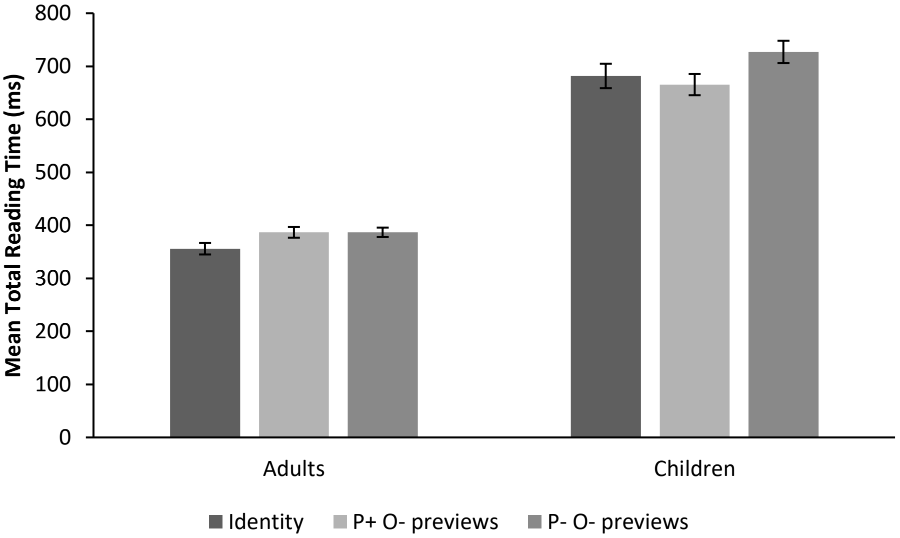
(c)


Mean Gaze Duration (ms)
0
50
100
150
200
250
300
350
400
450
500
Adults
Children
Identity
P+ O- previews
P- O- previews

(d)


Mean Selective Regression Path Duration (ms)
0
100
200
300
400
500
600
Adults
Children
Identity
P+ O- previews
P- O- previews

(e)


Mean Total Reading Time (ms)
0
100
200
300
400
500
600
700
800
Adults
Children
Identity
P+ O- previews
P- O- previews

Note. The error bars represent standard error.

The children's data were largely consistent with the adults'; reading times were disrupted after P+ O- previews relative to the identity condition (with the exception of total reading time). With respect to the second substituted letter condition, there were some differences (see Tables 5 and 6). Whilst numerical differences show that both groups displayed longer reading times following P- O- previews than identity previews (see Table 4), the magnitude of the effect was smaller in the children's data for early measures of processing (reflected in the significant interaction terms for "Children × P- O-").

Given the multiple comparisons undertaken within Model 1, we also ran Model 1 (without the intercept) for each dependent measure using the *glht* function (package multcomp) to adjust our *p* values for multiple comparisons (Hothorn et al., 2008). Two effects went from being significant to non-significant after using this correction technique: within gaze duration and selective regression path duration the interactions "Children × P- O-" became non-significant (p = .125 and p = .184, respectively). These analyses, therefore, also show that both adults and children displayed longer reading times after both letter substitution previews compared to an identity preview.

Critically, the contrasts show that adults did not benefit from the first letter's phonology being preserved in preview within early processing (they displayed similar reading times between the P+ O- previews and the P- O- previews; only in the later measure of selective regression path duration was there any difference between these two substitution conditions). Similarly, the children did not show any advantage from the preservation of the first letter's phonology in early measures of processing (see Tables 4 and 5, and Figure 1). In the later measures of selective regression path duration and total reading time, though, the children did benefit from the first letter's phonology being maintained in preview: they displayed faster reading times after P+ O- previews compared to P- O- previews (see Tables 4 and 6, and Figure 1).

Again, given the multiple comparisons undertaken within the key contrasts, we also ran the contrasts (without the intercept) for each dependent measure where there was a significant result present using the *glht* function (package multcomp) to adjust our *p* values (Hothorn et al., 2008). In this analysis, the difference between the two letter substitution conditions in children's selective regression path duration approached significance ($p = .075$). Critically, the benefit from phonology in preview was absent within early measures of processing; the benefit was consistently observed in total reading time.

Bayesian Analyses

Of critical interest within our results was the null effect of the first letter's phonology being preserved in preview (the comparison of the two letter substitution preview conditions). Consequently, Bayesian analyses were conducted to assess the strength of the evidence for the null and alternative hypotheses, wherever null effects were present within the contrasts. The analyses were conducted using the BayesFactor package (Morey & Rouder, 2013), for the Cauchy priors on effect size the default scale value (.5) was used, and 100,000 Monte Carlo iterations were specified. A low Bayes factor (< 1) indicates evidence for the null hypothesis and a high Bayes factor (> 1) provides evidence for the alternative hypothesis. For all models/contrasts items and subjects were specified as random factors.

Within the contrasts we examined any null effects that were present within each measure by comparing a specified model, which coded the two experimental preview conditions (P+ O- and P- O-) separately for the adults and the children (*PhonAdults*/*PhonChildren*), against the default intercept only model. The Bayes factors from the analyses were .16 for the adults in first fixation duration, .14 for both the adults and the children in single fixation duration, .27 for the adults and .07 for the children in gaze duration, and .07 for the adults in total reading time. 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, these Bayesian analyses indicate substantial evidence (and in the case of children's gaze durations and adults' total reading times, strong evidence) for the null hypothesis (i.e., the adults and the children were not gaining a significant benefit from the first letter's phonology being maintained in preview).

We also conducted Bayesian analyses on the null interactions within Model 1, in order to determine whether the children were indeed patterning like the adults. These null interactions were examined by comparing a model that specified the fixed factors of group and condition (e.g., *Group + condition*) with a model that additionally contained an interaction term (e.g., *Group + condition + Group:condition*). The Bayesian analyses indicated substantial or strong evidence for the null hypothesis regarding the interactive term between group and P+ O- previews (.09 for first fixation duration, .15 for single fixation duration, .12 for gaze duration, and .47 for selective regression path duration), and substantial evidence for the null hypothesis regarding the interactive term between group and P- O- previews in total reading time (Bayes factor = .14). This suggests that, overall, the children's parafoveal pre-processing of these preview conditions was consistent with the adults' pre-processing within these measures (i.e., like the adults, the children were displaying a cost from substituted letter previews compared to an identity preview).

Discussion

We investigated the first-letter bias within parafoveal pre-processing, examining what drives this effect during silent sentence reading: orthographic or phonological encoding. We compared the effects of our manipulations in skilled adult and beginner child readers. Firstly, as predicted, we found significant group differences: the children displayed significantly longer reading times than the adults, consistent with past research (e.g., Blythe & Joseph, 2011). The children's rate of lexical processing during reading was slower, and less efficient, than that of the adults, consistent with simulations of adults' and children's eye movement behaviour during reading within the E-Z Reader model (Mancheva et al., 2015; Reichle et al., 2013).

Nevertheless, as predicted, both the adults and the children displayed a first-letter bias: when the first letter was substituted in preview, compared to the identity condition, this disrupted their ability to lexically identify word *n*+1 (consistent with past research; e.g., Milledge et al., 2020). Moreover, as predicted, comparison of the two experimental preview conditions elucidated the cause of the first-letter bias. Within both adults' and children's first-pass reading, there was no evidence of the first-letter bias being phonologically driven; rather, the data are indicative of, primarily, orthography driving the importance of the first letter in preview. This may seem, at first glance, to contradict past research that has shown that skilled adult and beginner child readers process phonological information from word *n*+1 (e.g., Milledge et al., 2021; Pollatsek et al., 1992); however, upon closer inspection of the experimental manipulations and patterns of effects, it seems that any benefit from phonology in preview is dependent upon access to the correct orthographic code of the first letter.

Research findings are consistent with this idea of the first letter playing a vital role in facilitating readers' ability to benefit from phonology in preview. Pollatsek et al. (1992) found that adult readers, on average, did not display as much benefit from homophone previews over spelling control previews when the first letter of a target word was substituted in preview (e.g., *c* substituted with *s* in preview; *shoot* vs. *shout* as previews for *chute*), in comparison to when the first letter was maintained in preview (e.g., *beech* vs. *bench* as previews for *beach*)- 20 ms benefit vs. 37 ms benefit in first fixation duration, respectively (Experiment 2). Similar effects have also been found within children. Milledge et al. (2021)

found that, especially within the early processing of their orthographically dissimilar previews (half of these previews involved the substitution of at least the first letter), the children did not gain a benefit from intact phonology in preview. The children displayed longer reading times on pseudohomophone previews than spelling control previews (e.g., *kley* vs. *bloy* as previews for *clay*). It would seem, therefore, that preserving the orthographic code of the first letter of word *n*+1 in preview facilitates the efficient extraction of phonological information from that word for both adults and children.

Indeed, within the present research, we found no differences between reading times on target words after P+ O- previews compared to P- O- previews within the adult readers' early processing; indicating that the first-letter bias was, primarily, orthographically, not phonologically, driven. Regarding the children, they even displayed longer reading times in early processing (first fixation duration) on P+ O- previews than P- O- previews. Strikingly, when incorrect orthographic information was present for the first letter in preview, the children were unable to benefit from the first letter's phonology being present in preview; in fact, they suffered a cost. Both the adults and the children were unable to efficiently make use of the correct phonological information of the first letter being present in preview due to the orthographic manipulation of that letter, with this effect especially evident within the children. As such, the preservation of the orthographic code of the first letter would appear to be critical to both adult and, potentially especially, child readers' parafoveal pre-processing and early lexical identification processes within English, broadly consistent with past research (Milledge et al., 2021; Pollatsek et al., 1992).

Within both adult and child readers, the first letter's orthographic code would appear to be activated first, followed by its phonological code (e.g., Grainger et al., 2016). Given the notion that, within the lexicon, orthographic lexical representations activate phonological lexical representations (e.g., Perry et al., 2007), when the adult and child readers had, for example, *sircle* as a preview for *circle*, within the lexicon orthographic lexical representations for word *n*+1 would have been, incorrectly, activated for words beginning with *s*. Consequently, despite intact phonological information being present, the presence of incorrect orthographic information (having the first letter *s* in preview rather than *c*) caused an immediate cost to both the adults' and the children's ability to lexically identify word *n*+1. This could have been further compounded by the nature of the English language and its inconsistent GPCs: for example, *c* can have a /s/ sound or a /k/ sound and *g* can have a /j/ sound or a /g/ sound. When readers came to directly fixate the correct target word, in addition to the subsequent need to activate correct orthographic lexical representations (e.g., representations for words beginning with *c* rather than *s*), this would have resulted in the activation of multiple phonological lexical representations, given the first letter substitutions made within the P+ O- previews had more than one sound associated with them. Thus, readers would have been faced with an increasing number of competing lexical representations. Essentially, the unpredictable and complex nature of English (e.g., Schmalz et al., 2015) could have caused extra processing costs for the readers, with the first letter driving this cost.

As such, caution should be taken with regard to how generalisable these results might be to other languages with more consistent GPCs. At present, no research has directly demonstrated a first-letter bias within parafoveal pre-processing, using letter substitutions, within such languages (e.g., German, Finnish, etc.). Tiffin-Richards and Schroeder (2015) did, however, find that German children displayed longer reading times when the first two letters of target words were transposed in preview in comparison to an identity condition (e.g., *Abnd* as a preview for *Band*), with German adults also displaying this effect in one measure. They also found that both adults and children displayed longer reading times on substituted letter control previews (for the transposed letter previews; e.g., *Abnd*) compared to the identity condition (e.g., *Khnd* as a preview for *Band*), though this was not formally tested. This suggests that within languages with more consistent GPCs, like German, the first letter might also play an important role in preview. Tiffin-Richards and Schroeder's study also showed that whilst children displayed a benefit from phonology in preview, the adults did not. In contrast, the adults seemed to undertake more pre-processing of orthography than the children. This suggests that phonology plays an important role in preview for children reading in more consistent orthographies, with this changing developmentally to an increasing reliance on orthography. It is possible, therefore, that for children reading in languages with more consistent GPCs, the first-letter bias could be phonologically driven (or at least not lead to a cost over a control preview in early processing); whilst for adults, similar results to the present study could be expected to be found (i.e., the importance of the first letter being primarily orthographically driven). In addition, languages with more consistent GPCs are likely to be far less constrained as to the letter substitutions that can be made with regard to the first letter and maintaining a target word's phonology in preview; in comparison to the two letter substitutions we were constrained to (*c* substituted with *s*, and *g* substituted with *j*), also affecting the generalisability of our results. Consequently, this would be a worthwhile avenue of research in the future.

Overall, the present findings regarding a first-letter bias being present within both skilled adult and beginner child readers, and the primarily orthographically driven nature of this bias, are consistent with models of orthographic encoding (e.g., Grainger & Ziegler, 2011; Spatial Coding model, Davis, 2010; SERIOL, Whitney, 2001). We note again, though, that these models relate to isolated word identification under direct fixation and can, therefore, only make inferences about how this might extend to processing of word *n*+1 within natural sentence reading. Nonetheless, the early orthographic nature of the first-letter bias found is consistent with the SERIOL (Whitney, 2001) and Spatial Coding (Davis, 2010) models of visual word recognition. Both models posit that the first letter plays an important role in word identification processes, given sequential processing of letters within a word (Whitney, 2001) and dynamic end-letter marking (Davis, 2010); within both models the first letter receives increased activation/weight.

Regarding how these results relate to Grainger and Ziegler's (2011) model, the adults and the children appeared to display similar processing within their fine-grained routes (as previously found by Milledge et al., 2021). Both the adults and the children displayed an immediate cost when phonology was maintained in preview, requiring some form of sublexical conversions of print-to-sound to be undertaken for word *n*+1, but orthography was manipulated (P+ O- previews). This is as would be expected given the fine-grained route's limited flexibility with regard to orthographic encoding. Within both the skilled adult and beginner child readers' early processing within the fine-grained route, the presence of the first letter's correct orthographic code would appear to be key to the orthographic encoding that takes place in order to achieve lexical identification, with the correct orthographic code enabling effective, and efficient, processing of phonology. For both adult and child readers, any benefit from the first letter's phonology being maintained in preview was only present within later measures of processing (in selective regression path duration for both adults and children, and in total reading time for children). The onset of phonological processing occurring slightly later than that of orthographic processing is consistent with past research with adult readers (e.g., Lee et al., 1999), with the present study demonstrating similar effects within children as well. This late occurrence of the benefit from the first letter's phonology in preview highlights the inefficiency with which phonological information could be extracted from word *n*+1 by readers of English when incorrect orthographic information was present in preview.

We also found differences, as predicted, in the time course of parafoveal pre-processing between adult and child readers. We do note that past research suggests that spatial parameters might also affect parafoveal pre-processing. For example, children typically have shorter saccadic amplitudes than adults and make more fixations (e.g., Blythe et al., 2015; Pagán et al., 2021). A consequence of this may be that launch sites for saccades onto the target word are shorter for children than adults (i.e., children’s fixations on word *n* are closer to the end of that word and, thus, closer to the beginning of target word *n*+1, facilitating parafoveal pre-processing; e.g., Blythe et al., 2015; Fitzsimmons & Drieghe, 2011; Pagán et al., 2021; Tiffin-Richards & Schroeder, 2015). Within the present research, this would suggest that the children should have displayed more parafoveal pre-processing than the adults (i.e., displayed more of a cost to their processing). We, however, found the opposite, which suggests that differences within parafoveal pre-processing were primarily temporally based. The adults and the children differed in the time course of their processing of P- O- previews (where both phonology and orthography were manipulated); although the children showed numerical costs, they were less affected than the adults, within early processing, by these previews compared to the identity previews. Within Grainger and Ziegler’s (2011) model, the coarse-grained route would have been used for these previews, which allows more flexibility with regard to orthographic encoding. This flexibility could be increased by children’s orthographic representations being encoded with less precision compared to those of adults (e.g., Perfetti, 2007), as research suggests that readers with more precise lexical representations are more able to extract information from word *n*+1 (e.g., Veldre & Andrews, 2015). The adults with their more precisely encoded orthographic representations, would be more reliant on whole-word orthography in preview (as provided by the identity previews); whilst for children, if orthographic forms are less precisely encoded, less of an immediate cost would be expected when orthography is manipulated in preview, within the coarse-grained route. Broadly consistent with the findings of Milledge et al. (2020), this is suggestive of developmental change within the tuning of orthographic processing (e.g., Castles et al., 2007). Moreover, this suggests that 8- to 9-year-old child readers of English might still be developing their coarse-grained routes of processing (Grainger & Ziegler, 2011), with, presumably, this development continuing over time, as beginner readers progress to be skilled readers and develop higher quality lexical representations (e.g., Perfetti, 2007).

In conclusion, the present experiment provides novel evidence of the first-letter bias in parafoveal pre-processing being orthographically driven for both adults and children. Moreover, this experiment also provides novel insight into the time course of both adults' and children's ability to extract phonological information from the first letter of a word in preview when its orthography is manipulated. Of note, overall, is the critical role the first letter's orthography plays in preview, facilitating both adults' and children's efficient- early-processing of phonology in English.

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Sara Milledge was funded by an Economic and Social Research Council Studentship [grant number ES/J500161/1].

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Appendix A

Experimental sentences and preview conditions (P+ O- and P- O-):

(Note that the sentence frames are grouped here by target word but this was not how they were presented to participants)

We ran in a huge circle round the school field in PE.

The dancers were in a large circle on the stage.

I painted a blue circle on the mug I made for mum.

(*sircle*, *nircle*)

Hannah ate the tasty cereal for breakfast today.

My dad got the full cereal box out of the cupboard.

It is not healthy to eat sugary cereal every day.

(*sereal*, *nereal*)

The bright circus posters were very easy to spot.

Tom heard about the best circus from his friends.

It is exciting when the famous circus comes to town.

(*sircus*, *wircus*)

David didn’t like the mean giant in the film.

They were glad when the young giant helped them.

The happy giant was always eager to make friends.

(*jiant*, *yiant*)

The baby fell asleep after many gentle songs.

My aunt gives me a warm gentle hug whenever I see her.

The lady spoke with a very gentle voice to me.

(*jentle*, *pentle*)

The zookeeper fed the hungry giraffe lots of hay.

The story about the baby giraffe was in the newspapers.

Ben enjoyed seeing the tall giraffe at the zoo.

(*jiraffe*, *piraffe*)

I know that some germs can make you very poorly.

There are bad and good germs inside your tummy.

The teacher's lesson about germs was very interesting.

(*jerms*, *yerms*)

The bus travels between the three cities very slowly.

The bridge between the busy cities was always blocked.

Tim really didn’t like the noisy cities at night.

(*sities*, *vities*)

We walked towards the town centre very slowly.

We rode to the city centre on our bikes last night.

Jim helps at an animal rescue centre on weekends.

(*sentre*, *zentre*)

The story was about a brave genie who saved the day.

I jumped when the evil genie appeared out of nowhere.

The magic genie helped us on our way when we got lost.

(*jenie*, *yenie*)

We learned about the last century in history lessons.

I read about the past century in a library book.

The next century should bring exciting new discoveries.

(*sentury*, *xentury*)

The crafty gerbil had managed to escape again.

Sam watched the speedy gerbil run around its cage.

Last night the clever gerbil dug a very long tunnel.

(*jerbil*, *yerbil*)

The girl was a real genius when it came to maths.

Only a true genius could solve the difficult puzzle.

The clear genius of the person was clear to everyone.

(*jenius*, *yenius*)

The city’s small central area was easy to find.

The town’s central square was beautiful in summer.

The book's central character was very popular.

(*sentral*, *mentral*)

The children had many general ideas for the show.

The directions were very general and we got lost.

Lucy asked for some general information about the area.

(*jeneral, peneral*)

We became less certain of who would win the prize.

I was quite certain that I knew the right answer.

The man was almost certain he’d made the right choice.

(*sertain, mertain*)

The small cinema was always busy at weekends.

Sally went to the quiet cinema with her friends.

They built a new fancy cinema and some shops in town.

(*sinema, rinema*)

Appendix B

Supplementary tables, figures, and analyses

Table B1

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

Single fixation probability	Condition	Adults	Children
	Identity	.78 (.85)	.59 (1.52)
	P+ O-	.76 (.79)	.57 (1.37)
	P- O-	.76 (.89)	.52 (1.62)

Table B2

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

Percentage of skips	Condition	Adults	Children
	Identity	7.91% (.27)	4.28% (.20)
	P+ O-	5.77% (.23)	2.53% (.16)
	P- O-	4.47% (.21)	3.52% (.18)

Table B3

Output from Model 1 and the Contrasts for Selective Regression Path Duration and Total Reading Time, using the contr.sdif Function for Presentation

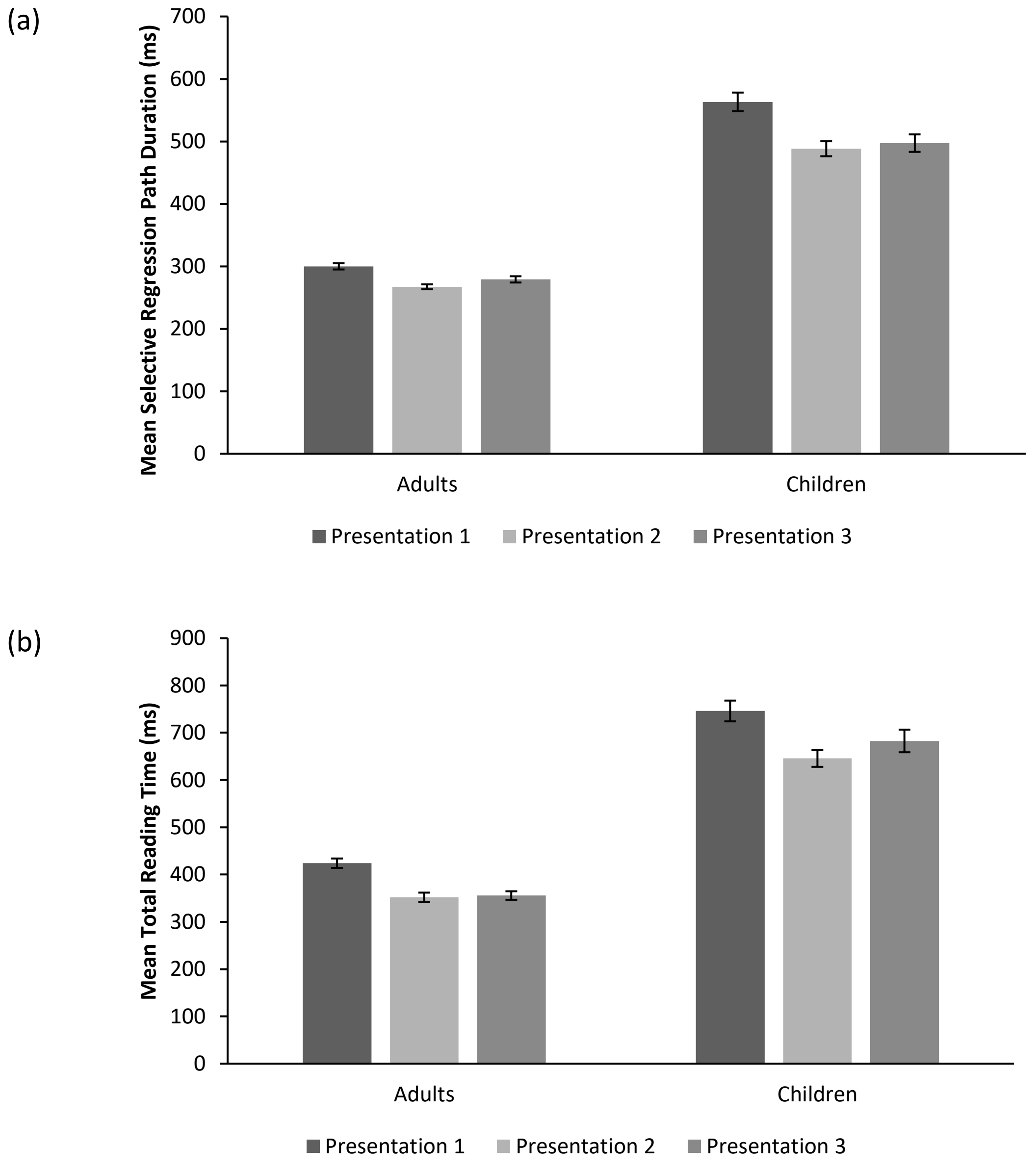
	Selective regression path duration				Total reading time			
	b	SE	*t*	*p*	*b*	*SE*	*t*	*p*
Adults, Identity (Int)	5.47	.05	112.65	< .001	5.69	.06	101.99	< .001
Group (Adults vs. Children)	**.58**	**.06**	**9.03**	**< .001**	**.60**	**.07**	**8.21**	**< .001**
Adults, P+ O-	**.10**	**.03**	**3.88**	**< .001**	**.11**	**.03**	**4.16**	**< .001**
Adults, P- O-	**.16**	**.02**	**6.54**	**< .001**	**.13**	**.03**	**4.82**	**< .001**
Presentation 1-2	**-.11**	**.02**	**-6.35**	**< .001**	**-.16**	**.02**	**-8.21**	**< .001**
Presentation 2-3	.01	.02	.32	.750	.001	.02	.05	.963
Children × P+ O-	-.07	.04	-1.78	.079	**-.11**	**.04**	**-2.75**	**.006**
Children × P- O-	**-.07**	**.03**	**-2.12**	**.037**	-.05	.04	-1.20	.230
Contrasts								
Intercept (grand mean)	5.82	.04	132.55	< .001	6.05	.05	120.28	< .001
Adults, P+ O- vs. P- O-	**-.06**	**.02**	**-2.58**	**.010**	-.02	.03	-.66	.508

Children, P+ O- vs. P- O-	**-.05**	**.02**	**-2.33**	**.020**	**-.08**	**.03**	**-2.94**	**.003**
Presentation 1-2	**-.12**	**.02**	**-7.51**	**< .001**	**-.16**	**.02**	**-8.17**	**< .001**
Presentation 2-3	.01	.02	.62	.537	.0003	.02	.01	.989

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 *contr.sdif* function (package MASS) was used to set up presentation as a factor. Following trimming, the syntax for selective regression path duration was: *depvar* ~ *Group* * *condition* + *presentation* + *(1* + *condition|Participant)* + *(1|targetno)*, and the syntax for total reading time, as an intercepts only model, was: *depvar* ~ *Group* * *condition* + *presentation* + *(1|Participant)* + *(1|targetno)*. Within the contrasts, after trimming, the syntax for selective regression path duration and total reading time, as intercepts only models, was: *depvar* ~ *GroupByCond* + *presentation* + *(1|Participant)* + *(1|targetno)*.

Figure B1

Mean Selective Regression Path Durations (a) and Total Reading Times (b) on First, Second, and Third Presentations of Target Words for Both Adults and Children



Note. The error bars represent standard error.