Phonological and Attentional effects of the First Letter Advantage

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Introduction

For all readers, visual word recognition starts with the identification of individual letters within a word. Early readers will scan letters from left to right, converting each letter from its orthography to its phonetic translation until the word is 'sounded out'. Skilled readers, however, rapidly decode letter identity and position from only a single fixation lasting around 200 ms (Rayner, Slattery, & Bélanger, 2010). The mechanisms responsible for encoding the identities and positions of letters in fluent readers are the subject of some debate. For example, the amount of information provided by each letter is not equal, and while existent theories generally agree that letters are processed in parallel (Adelman, Marquis, & Sabatos-DeVito, 2010; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989), there is strong evidence that the efficiency of processing is dependent on letter position (Davis, 2010; Whitney, 2001).

Early work on letter position mechanisms used a masked prime paradigm with a post-cued letter-in-string task. The task begins with a briefly presented backwards masked string of letters, followed by a forward mask and a visual prompt at one of the letter positions. Participants report which letter was present at the cued location, and accuracy and reaction times are measured (Tydgat & Grainger, 2009). This procedure, and similar variants (Marzouki & Grainger, 2014), have found reliable effects of letter position on the accuracy of response as well as speed of reaction time. A higher accuracy and lower response times of the first letter, commonly referred as the first-letter advantage, and to a lesser extent the last letter, are consistently reported (Grainger, Bertrand, Lété, Beyersmann, & Ziegler, 2016; Scaltritti, Dufau, & Grainger, 2018; Tydgat & Grainger, 2009). It was proposed that since external letters experience less lateral interference from flanking letters, an effect known as crowding (Pelli, Palomares, & Majaj, 2004), that they would have greater identifiability (Grainger, Dufau, & Ziegler, 2016; Tydgat & Grainger, 2009). Additionally, the fixated letter, which is the central letter of a word in this experimental design[1], has an advantage in accuracy and reaction time, thought to be a product of a higher signal in foveated positions. Together, these effects result in a 'W' shape for accuracy across letter position, and an 'M' shape for reaction times. Number strings also show this pattern, while symbols and shapes retain only the fixated position advantage (Tydgat & Grainger, 2009).

It has been suggested that the letter-in-string paradigm places an excessive emphasis on single letters, unrealistic to natural reading (Scaltritti & Balota, 2013), and the whole word approach developed by Adelman et al. (2010) would be more appropriate. The whole word paradigm differs by having participants select from two words, one identical to the primed word and a foil which differs by one letter, in place of cuing a letter position (Adelman et al., 2010). This paradigm reports a strong first letter advantage, similar to the letter-in-string task, and robust to changes across word length (Scaltritti & Balota, 2013) and orientation (Aschenbrenner, Balota, Weigand, Scaltritti, & Besner, 2017). However, none of the whole word experiments have found a strong effect at fixation or for the last letter position. Instead, a left-to-right linear decrease in accuracy is typically found (Adelman et al., 2010; Aschenbrenner et al., 2017; Scaltritti & Balota, 2013). Some suggesting that the letter-by-letter and whole word paradigms may not be measuring the same processes (e.g. Aschenbrenner et al., 2017).

The first letter advantage, having survived both paradigms, attracted several accounts of the effect. First, the modified receptive fields hypothesis (MRFH), suggests an adaptive modification of the receptive fields during reading acquisition in favor of the initial letters (Chanceaux, Mathôt, & Grainger, 2013; Grainger, Bertrand, et al., 2016; Tydgat & Grainger, 2009). Second, a phonological account of the first letter advantage has been considered. The Thai language was used to investigate phonological effects because it contains words with nonaligned phonological representations of the orthography. These words are pronounced with the second letter position as the first phoneme, followed by the phoneme of the first letter position (Winskel, Ratitamkul, & Perea, 2018).Thai also has aligned words which are pronounced sequentially from left to

[1] Fixations in natural reading are actually slightly to the left of center for left-to-right languages (Rayner, 1979)

right as in English. While a first letter effect was found for the aligned conditions, a second letter effect was found for the nonaligned conditions, even with nonword stimuli (Winskel et al., 2018). Thus, in Thai, there is a first *phonological* letter advantage. This is an interesting distinction, but the underlying process of the advantage remains hidden. Another effort conducted a same-different task with Japanese-English bilinguals (Lupker, Nakayama, & Perea, 2015). In the same-different task, a referent word is presented before the masked prime, the participant is tasked with reporting if this word matches the target, presented after the masked prime. The referent and target were both presented in English using the Roman alphabet, while the masked prime was presented as a transliteration of the target English word, or an unrelated English word, in Japanese Katakana. A phonological effect was found with the transliterated Katakana words, and since there is no orthographic overlap between the languages, the authors concluded that phonological information is utilized in the same-different task (Lupker et al., 2015). Critics point out that this design removes the possibility of orthographic effects, and when given an experiment with orthographic overlap, here both referent and target are presented in English, the phonological effect disappeared (Kinoshita, Gayed, & Norris, 2018; Kinoshita & Norris, 2009). The experiment used masked primes in English with a similar same-different task. The prime was either identical in orthography and phonology (identity condition, e.g. score-SCORE), identical in only phonology (pseudohomophone condition, e.g. skore-SCORE), or different in both orthography and phonology (control condition, e.g. smore-SCORE). Reaction times of both the phonology condition and control condition were consistently lower than the identity condition, but had little difference between themselves (Kinoshita et al., 2018). So, the same-different task within the same script generates a small phonological effect compared to the considerable effects found when orthographic overlap is removed.

In our first experiment, we attempted to replicate and further assess the phonological effects found in previous work. We used the whole word approach along with pseudohomophone pairs of consonant strings and pseudowords, and compared accuracies and reaction times against a control differing in both orthography and phonology. The whole word approach was used in place of the same-different task for two reasons: First, while the whole word and the same-different task are both a measure of orthographic coding, they are still fundamentally different tasks. If a masked prime in the whole word approach is encoded successfully, the accuracy of the response is expected to increase, conversely, the same-different masked primes are disruptive. Consistency between the paradigms would not only increase the evidence against a phonological account of the first-letter advantage, but also demonstrate some convergent validity between the paradigms. Second, the design of the same-different task requires three types of primes for evaluating phonolgical effects: an identity, a pseudohomophone, and a control, as defined earlier. If the pseudohomophone primes reduce the reaction time by a greater amount than the control relative to the identity, then an effect is present. A whole word approach requires only two conditions: one where the target and foil are both non-word homophones and another where the target and foil differ orthographically and phonologically. Thus, each condition is already a contrast between the identity (match between prime and target) and the experimental manipulation (match between prime and foil). A comparison between these two groups is statistically more powerful relative to the the same-different paradigm with three groups.

A third account of the first letter advantage suggests a flexible attentional mechanism, independent of word orientation, to facilitate activation of the initial letter (Aschenbrenner et al., 2017). Aschenbrenner et al. (2017) used a variant of the whole word masked priming paradigm in which primes were presented in a random orientation (horizontal or vertical). A comparable first letter advantage was found for both horizontally and vertically presented primes, a finding that conflicts with predictions of the MRFH. If visual acuity for the first letter has adapted to a horizontal reading orientation, then a vertical reading orientation should not produce the same effect, and certainly not at the same magnitude. However, when a similar orientation procedure was used with the letter-in-string paradigm, the horizontal condition did show a more robust first letter advantage compared to the vertically presented words (Scaltritti et al., 2018). The notably weaker effect for vertically presented stimuli admits some ambiguity to the evidence against the MRFH and leaves open the possibility that the first letter advantage is the result of an ensemble process.

Experiment 2 addresses the potential attentional effects of the first position advantage by using color to redirect attention to various letter positions. A whole word masked priming task was used with four conditions: number strings, consonant strings, pseudowords, and words, all 5 characters long. In some trials, a single letter/number of the masked prime was selected as the attentional distractor and it's color set to red. A different colored letter will produce a higher salience and attentional draw than the non attended characters defined by a constant color feature (Itti, Koch, & Niebur, 1998). All five letter positions had an equal number of trials with an attentional distractor, including a set of trials without any distractor. We categorized this manipulation into three groups: a no distractor condition where no letter was colored red, an attended condition where the manipulated letter/number position was the same as the distractor, and the non-attended condition where the manipulated position was not the same as the distractor position. A first-letter advantage in the no distractor condition but absent in the non attended condition would suggest not only a mechanism for the deployment of attention to the first position, but also that a nonconforming letter feature at a different position can disrupt the mechanism. However, if the first-letter advantage is still present in the non attended condition, we should not rule out attention. The attentional saliency of the first position may be greater than the difference in color at another position. Additionally, attention may be shared, with an increase in performance on the first letter position and the attended letter. The attended condition was used to evaluate where attention is being focused for each letter position across all character strings.

Experiment 1 (Phonology)

Methods

Participants. 28 participants were recruited from the University of California at Irvine student population through Human Subjects Lab Pool (18 females, 10 males). All reported normal or corrected to normal vision and reported a native level of English proficiency. All participants received course credit for their participation.

Materials. Stimuli consisting of five letter strings were generated for four conditions: matched phoneme pseudowords , mismatched phoneme pseudowords, matched consonant strings, and mismatched consonant strings. The pseudoword conditions were generated by algorithm starting with a list of five letter words and changing one letter to create a pronounceable pseudoword that would not violate phonotactic constraints. The letter was replaced with either c/k or j/g depending on if the created pseudoword would be pronounced the same way with both new letters. For instance, since the letter 'j' is pronounced with /ʤ/, a matching pronunciation with a 'g' is pronounced when the following letter(s) is an 'e', 'i', 'y', 'aw', or 'oe'. Similarly, the letter 'k' is pronounced with /k/ when it is not before an 'n', the letter 'c' will be pronounced with /k/ as long as it is not before 'e','i','y','ae', or 'oe'. For some G/J conditions, especially in the final letter conditions, there was an unavoidable difference in how a person might pronounce the pseudoword. The mismatched pseudoword condition was created by taking the same word used in the matching conditon at the same letter position, but changing the letter so that it would make two pseudowords pronounced differently from one another. The pseudowords were still under the restriction of being pronounceable, so two letters were manually selected from a limited pool of pronounceable options. The consonant string conditions were created by random combinations of 5 letter strings using a bank of 10 letters (c, k, j, g, b, s, l, v, d, and t). The randomization procedure required each letter to be present in each letter position an equal number of times. For the matched condition c/k and j/g were once again used. Ten stimuli were generated for each letter pair, at each letter position, for each condition, totaling 400. For each pair, one word was randomly selected as the target and the other as the foil. The words were counterbalanced across subjects so that every word served as target and foil an equal number of times.

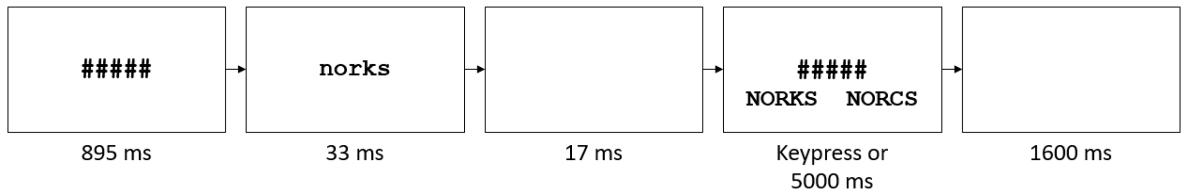

Figure 1. Procedure for Experiment 1. (1) A forward mask was presented for 895 ms consisting of a string of five hash marks at the center of the screen. (2) Prime presented for 33 ms in lower case letters. (3) Blank interstitial screen for 17 ms. (4) A backwards mask was presented in the same position as the first along with the target word and foil in upper case letters for 5000 ms or until the participant made a selection. (5) A blank intertrial screen presented for 1600 ms.

Procedure. The procedure approximates the one used in Scaltritti and Balota (2013) and Adelman et al. (2010). The procedure is outlined in Figure 1. First, a string of five hashmarks was displayed at the center of the screen for 895 ms, the target word was then displayed in the center of the screen in lowercase letters for 33 ms, then a blank screen for 17 ms, and finally another string of five hashmarks at the center of the screen with both the target and the foil displayed underneath in capital letters. The participant was instructed to press the z key to select the word on the left or the m key to select the word on the right. These words were displayed to the left or right side of the screen randomly. If the participant did not make a selection after 5000 ms, the trial was skipped. After each trial a blank intertrial interval was displayed for 1600 ms. 12 practice trials were presented at the beginning of the experiment to get participants used to the speed of presentation. This was followed by five blocks of 80 randomly selected trials (20 per condition). After each block, the participants were given feedback on the accuracy of their responses.

Results

Data preparation was as follows. First, we removed all trials where a selection was not made within 5 seconds (0.17% of all trials). Second, a log transformation was applied to the reaction time data to approximate the normal distribution assumption of linear models. Reaction times that were less than 250 ms were excluded to further improve the distributional assumption (0.95% of all trials). 250 ms was selected as a cut off from a visual inspection of the normal Q-Q plot of the log-transformed reaction times similar to Kinoshita et al. (2018).

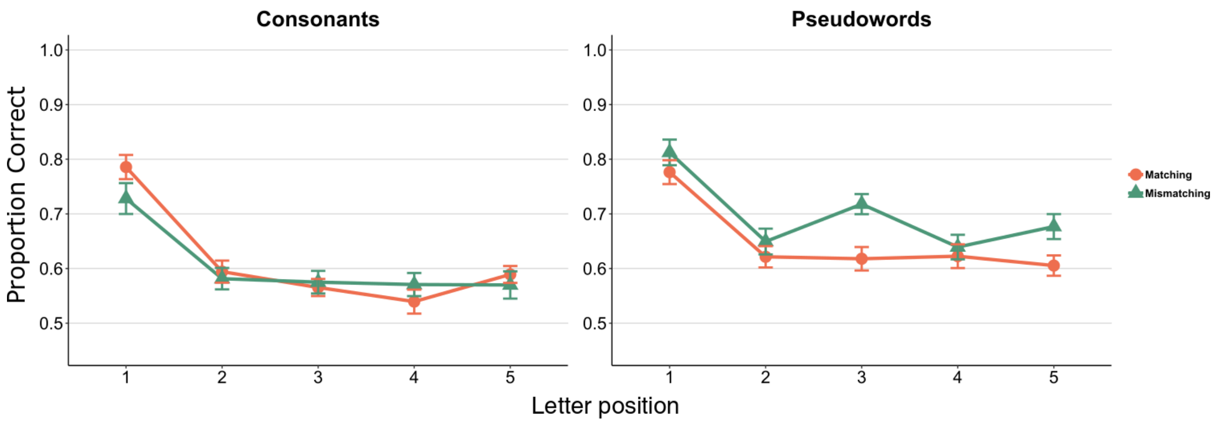

Figure 2. Experiment 1 (accuracy): Mean proportion of correct responses with respect to letter position across two conditions: Matching phonology and mismatching phonology. Error bars are the within-subject standard error of the mean (**?**).

Accuracy was modeled using a generalized linear mixed effects model created in the Stan computational framework ((Carpenter et al., n.d.)) using brms (Bürkner, 2018)) in R (R Core Team, 2013). The model used was: correct ∼ position + position:condition + (1|participant). Interaction terms represent the contrast between the matching and mismatching condition at each letter position. A main effect of condition was left out so that the size of the effects between the matching and mismatching conditions could be interpreted clearly within the interaction effects of the categorical factorization of each letter position. Conservative priors were used to avoid overfitting.

Reaction time data were analyzed using a general linear mixed effects model with the log-transformed reaction times as the response variable: log(RT) ∼ position + position:condition + (1|participant). This model can be interpreted similarly to the GLMM for accuracy. Posterior contrasts across conditions and letter positions for both models gives the most credible model estimates and 95% credible intervals.

For the pseudoword condition, the first letter position was answered 16.48% (11.02, 21.65), 9.88% (4.86, 14.83), 17.75% (12.55, 23.13), and 13.95% (8.78, 19.12) more accurately than letter positions two through five, and letter position 3 was 6.49% (0.92, 12.00), and 7.83% (2.44, 13.30) more accurate than letter positions 2 and 4 respectively. The reaction times for position one were also all faster than positions two through five (see Table 1 for all posterior letter position contrasts). The most credible difference between the mismatching and matching condition at position 3 was 9.98% (4.46, 15.56) in favor of the mismatching condition. For position 5, participants responding to the mismatching condition performed higher by 6.86% (1.25, 12.62) compared to the matching condition. Position 1 had a smaller effect at 4.00% (-0.55, 8.80) in favor of the mismatching condition.

For the consonant string condition, letter position one was 14.55% (9.15, 20.07), 15.53% (10.19, 20.79), 15.76% (10.34, 21.20), 16.15% (10.63, 21.57) more accurate than letter positions two through five. The reaction times for the first letter were once again faster than letter positions two through five (see Table 2). The first letter position of the matching condition was 6.28% (1.32, 11.11) more accurate and 76.7 ms (9.8, 140.3) faster than the mismatching condition.

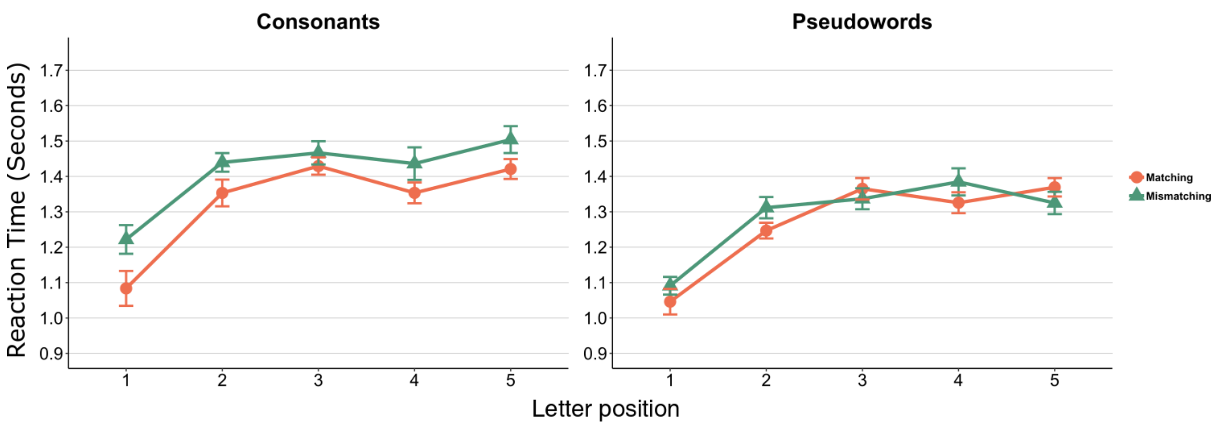

Figure 3. Experiment 1 (reaction times): Mean reaction times (seconds) with respect to letter position across two conditions: Matching phonology and mismatching phonology. Error bars are the within-subject standard error of the mean (**?**).

Discussion

A clear first letter advantage was found for the mismatching control for both the consonant strings and the pseudowords, for both accuracy and reaction time. For pseudowords, we found a robust effect in the fixated letter position (third) and slightly smaller effect in the final (fifth) position for accuracy but not reaction time. The characteristic 'W' shape found with pseudowords is consistent with the results of the letter-in-string task (Grainger, Tydgat, & Isselé, 2010; Tydgat & Grainger, 2009), but only for the control condition with mismatching phonology. Interestingly, the effect at fixation for pseudowords was not found in similar experiments (Scaltritti & Balota, 2013) and the absence has been used as evidence that the letter-in-string and whole word procedures measure different processes (Aschenbrenner et al., 2017). Crucially, the improvement at the fixated and final letter seen in the mismatching condition are absent for the matching phoneme condition. Small differences between the matching and mismatching condition for the first letter in pseudowords is weak evidence for a phonological account of the first-letter advantage. For consonant strings, an effect in the opposite direction was found, where the matching phonology condition performed better at the first position.

Experiment 2 (Attention)

Methods

Participants. 30 participants were recruited from the University of California at Irvine student population through Human Subjects Lab Pool (23 females, 7 males). All reported normal or corrected to normal vision and reported a native level of English proficiency. All participants received course credit for their participation.

Materials. Stimuli were generated for four conditions, each five characters long: words, pseudowords, consonant strings, and number strings. The consonant condition was created by randomly generating 5 letter strings from the 9 possible consonants used in Experiment 1. The randomization procedure ensured that every consonant appeared 6 times (5 attentional distractors and 1 control) for each letter position of interest. Every consonant was positioned in non critical positions an equal number of times. In total, 9 consonants, across 5 letter positions, and 6 attentional positions were used, for a total of 270 stims. The number strings were created by converting the consonant strings to numbers where each consonant was set to a number between 1 and 9. The word stimuli were selected from common five letter words in pairs, so that the words differ only by one letter. Priority was given to the pairs of words which had the highest minimum frequencies as reported by the Corpus of Contemporary American English Davies (2009). The pseudowords created in Experiment 1 were used for the pseudoword condition.

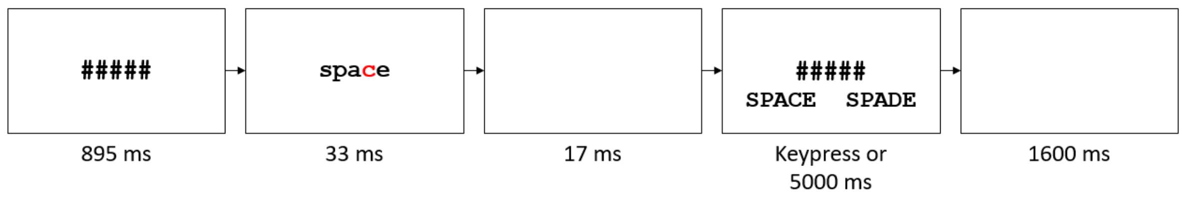

Figure 4. The procedure for Experiment 2 is the same as Experiment 1 except for an attentional distractor at each position made by changing the color of the letter. This is an example of an attentional trial, where the position of the attentional distractor matches the position of the unique letter between the words.

Procedure. The procedure was similar to the one used in Experiment 1 and is outlined in Figure 4. Each trial begins with a forward mask consisting of a string of five hash marks displayed in the center of the screen for 895 ms. The target word was then displayed in the center of the screen in the same space for 33 ms. If the condition involved an attentional distractor, a random letter was colored red. This was followed by a brief 17 ms interstitial screen. The participant was then shown a backward mask of five hashmarks with the target and foil displayed in all capital letters underneath, presented on the left and right side of the screen in a random order. Once again, the participant was instructed to press either the z key to select the word on the left or the m key to select the word on the right. If the participant did not respond within 5000 ms the trial was skipped. Each trial was separated by a blank screen for 1600 ms. The experiment began with 12 practice trials to adapt participants to the speed of presentation. The experiment consisted of 9 blocks of 120 randomly selected trials (30 for each condition), for a total of 1080 trials. Participants were given feedback on their accuracy after each block.

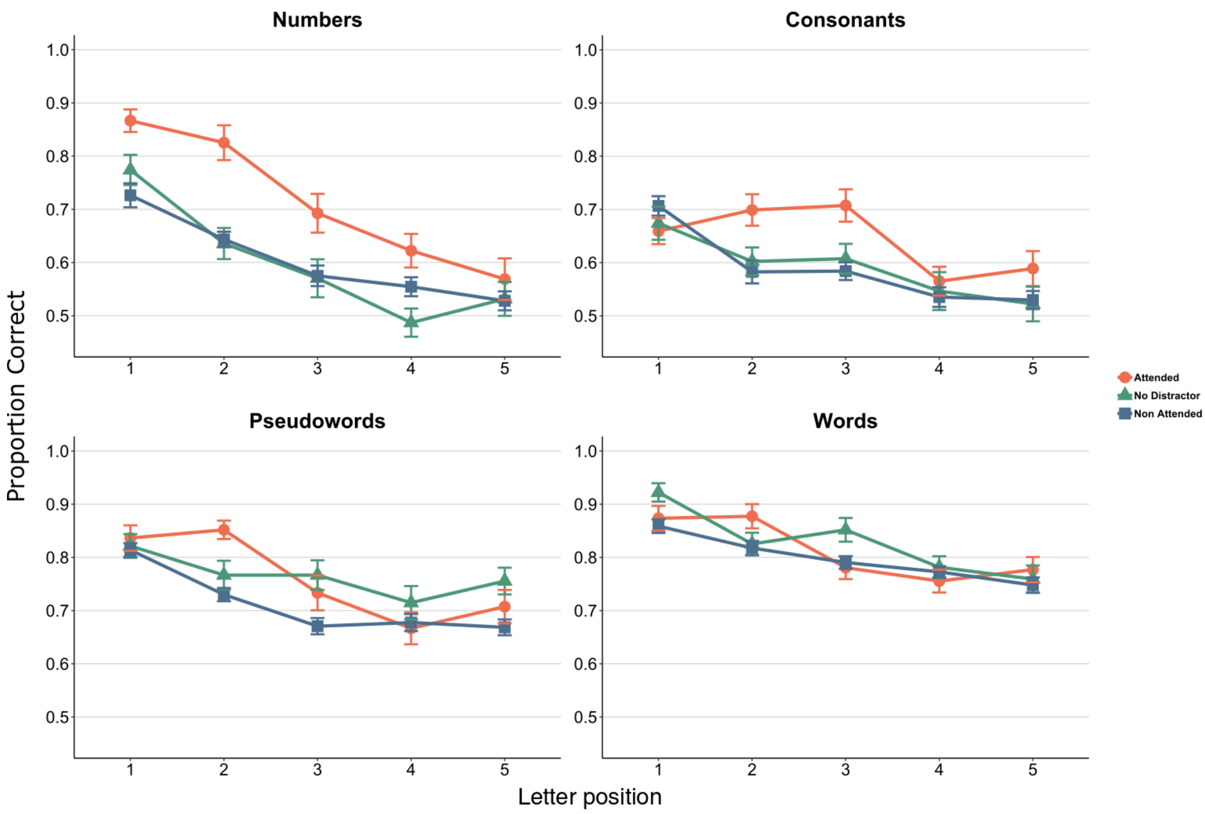

Figure 5. Experiment 2 (accuracy): Mean proportion of correct responses with respect to letter position across three conditions: attended, no distractor, and non attended. Error bars are the within-subject standard error of the mean (**?**).

Results

Data preparation was identical to Experiment 1. Reaction times that were less than 250 ms (0.21% of all trials) or greater than 5 seconds (0.16% of all trials) were excluded from analysis. Data was organized as follows: the attended condition consisted of trials where the manipulated letter was the same as the attended letter, the non attended condition consisted of all trials without an attentional distractor, and the non attended condition consisted of all trials where the manipulated letter position was different from the colored letter.

Accuracy and reaction times were modeled with an equivalent GLMM and GLM used in Experiment 1. For all stimulus types (numbers, consonants, pseudowords, and words), the reaction times for the first letter position in the no distractor condition was faster and more accurate than letter positions 2-5 (see Table 3). For words, the third letter position was 6.44% (-0.07, 12.78) more accurate than the fourth position and

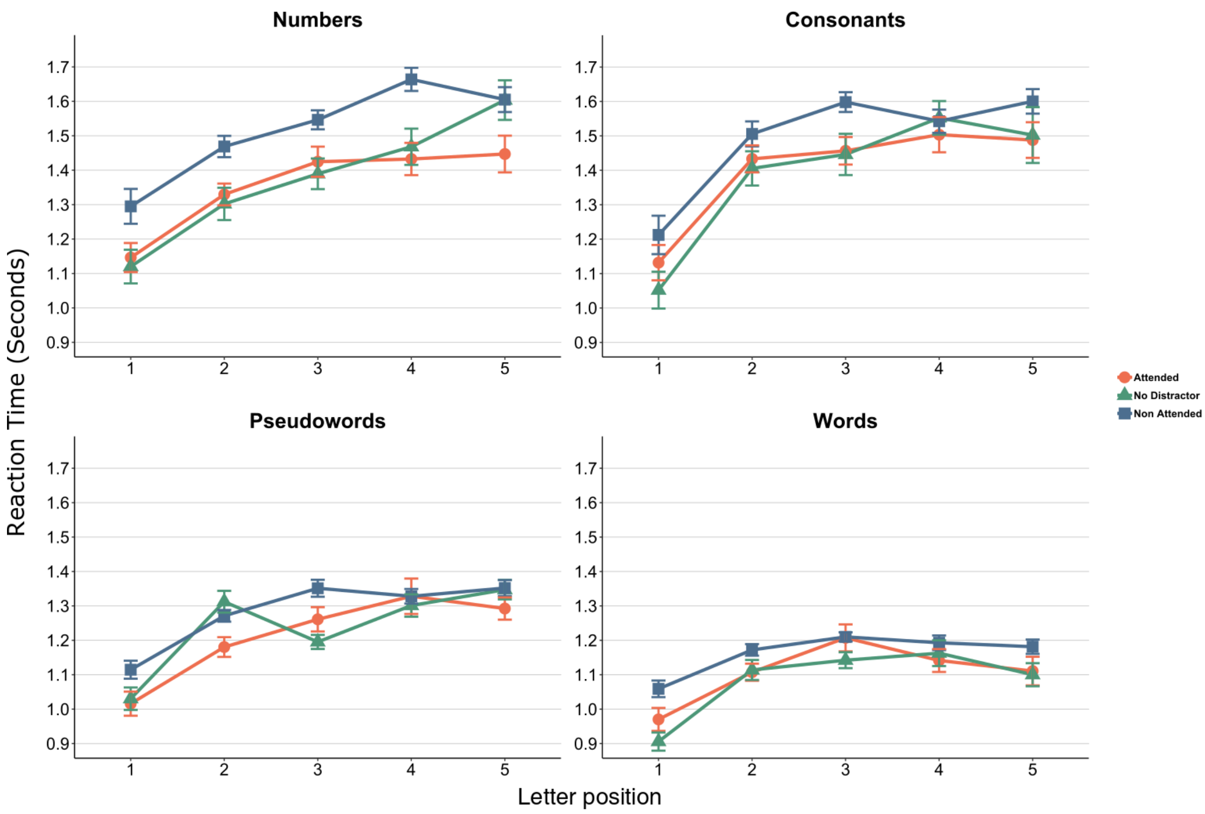

Figure 6. Experiment 2 (reaction times): Mean reaction time (seconds) of correct responses with respect to letter position across three conditions: attended, no distractor, and non attended. Error bars are the within-subject standard error of the mean (**?**).

8.96% (2.52, 15.49) more accurate than the fifth.

The primary contrasts of interest are those between the trials where no distraction was present, and conditions with non attended distractors. For the words at the first letter position, participants made the correct distinction 6.08% (2.33, 9.82) more often and responded 113.7 ms (70.2, 157.3) faster on trials that had no distator compared to non attended distractor trials. Similarly, the third position saw a reduction of 5.88% (0.72, 10.43) between the no distractor and non attended trials. All four stimulus types saw an slower reaction time in the non attended condition compared with the no distractor condition (see Table 4). The pseudowords condition showed a reduction in accuracy from the no distractor trial to the non attended trials at position 3 (9.88% [3.91, 15.69]) and 5 (8.89% [3.13, 14.59]).

Trials with attended distractor letters tended to have a higher average proportion correct relative to the trials with no distractor. For numbers, a strong effect is seen with the first (9.31% [2.79, 15.52]), second (19.11% [11.84, 26.50]), third (12.50% [4.50, 20.55]), and fourth (13.61% [5.44, 22.05]) letter positions. For consonants, the attended condition is 9.69% (1.75, 17.59) more accurate at position 2 and 10.02% (2.15, 17.73) more accurate at position 3 compared with the no distractor condition. The second position was also more accurate for pseudowords (8.52% [1.78, 15.35]) as well as a reasonably confident effect for words (4.89% [-0.77, 10.66]). Interestingly, the word conditions displayed the opposite pattern for letter positions one (-4.53% [-9.68, -.05]) and three (-6.58% [-12.87, -.24]).

Discussion

The primary motivation behind Experiment 2 was to examine an attentional account of the first letter advantage. The rapid deployment of attention proposed by Aschenbrenner et al. (2017), is supported for words from the decrease in accuracy for the first letter when a distractor letter is present. However, this effect was not found for numbers, consonants, or pseudowords, suggesting such a mechanism has less utility in fluent reading. As previously mentioned, letters from familiar words are processed in parallel whereas unfamiliar words and pseudowords are read left to right and letter-by-letter. Thus, attention to the first letter of a word may be less useful than to a number or nonword where reading from left-to-right is required. However, we are careful not to rule out the effects of attention for non word stimuli, and propose instead that attention was not sufficiently disrupted from the initial position of the non word conditions. For the fixated letter, an increased accuracy was found for words, and a decreased response time was found for pseduowords, once again demonstrating that the fixation effect is not unique to the letter-in-string paradigm.

The attended condition evaluated how directed attention can change the performance at a letter position. For numbers, we see a consistent increase in accuracy across all but the last letter position. Interestingly, we saw no improvement in reaction time, except for the last letter position, where accuracy was at its weakest improvement. The attended condition most consistently improved performance at the second letter position across all stimulus types. An attentional deployment to the beginning of a word might be more easily shifted to the second letter as seen in Winskel et al. (2018), and especially so when a conspicuous feature change is present. For words and pseudowords, with the exception of the second letter position, the attended condition was never helpful and usually disruptive. This finding suggests that drawing attention to a single letter of a pronounceable word or pseudoword will generally not assist in identifying a change at that letter position. Finally, we observed a left-to-right downward trend across letter position in numbers, consonants, pseudowords, and words, consistent with previous reports using the whole word paradigm (Adelman et al., 2010; Aschenbrenner et al., 2017; Scaltritti & Balota, 2013).

General Discussion

Elements of the first letter advantage were investigated using the whole word paradigm across two experiments. In Experiment 1, homophone pairs of pseudowords and consonant strings were used to investigate phonological effects of letter position as measured by relative accuracy and reaction times. Two conditions were used for comparison, a matching condition, where target and foil strings had a matching phonology and a differing orthography, and a mismatching condition, where target and foil differed by both phonology and orthography. In Experiment 2 a letter was randomly selected and colored red to act as an attentional distractor for the other letters, and compared against trials without distractors. Three conditions were used for comparison, an attended condition, including all trials where the attended letter matched the modified letter position, a non attended condition, including all trials where the attended letter did not match the modified letter position, and a no distractor condition, where no attentional distractor was used.

Key findings are summarized here: (1) The first letter advantage was reduced in words with an attentional distractor, but not with a matching phonology. (2) Counter to previous reports (Aschenbrenner et al., 2017; Scaltritti & Balota, 2013), the fixated letter had an advantage in pseudowords and words. (3) Performance for the fixated letter was reduced in words and pseduowords when the fixated letter was not the attentional distractor, and in pseudowords performance was reduced when the target and foil had matching phonology. (4) Drawing attention to the divergent letter in the second position consistently improved the accuracy of the second letter position across all types of stimuli.

The findings for the first letter advantage reported are largely in agreement with previous research. We report a weak phonological effect on the first letter for pseudowords in line with Kinoshita et al. (2018) and consistent with other phonological priming studies which have found only marginal effects of phonology (Rastle & Brysbaert, 2006). For attention, we report that the distracted condition in words reduce the accuracy of the first letter position by around 6%. While the size of the effect is not large, it reduces the pattern of accuracy in the first and third position down to a level that is approximately linear with the rest of the letter positions. As previously discussed, a downward left-to-right reduction in performance is thought to be due to efficiency of processing at each letter position independent of the first letter advantage (Adelman et al., 2010). Removing the source of the first letter advantage can only theoretically reduce the effect to a baseline efficiency level. For numbers, consonants, and pseudowords, no comparable decrease was found in the non attended condition. From the context of word recognition models, a word stimulus activates a lexical representation of the whole-word and feeds back information about letter identity (e.g. Coltheart et al., 2001). A route not available to nonword stimuli. The first-letter advantage in words, may be from an automatic attentional process for left-to-right reading that doesn't need to "turn off" unless presented with an attentional distractor. Conversely, the nonword stimuli does not disconnect its attention from the first position when presented with a distractor since there is no lexical activation to supplement identification.

The effect at fixation, reported in most letter-in-string paradigms (e.g. Tydgat & Grainger, 2009), has consistently been reported as absent from the whole word approach (e.g. Scaltritti & Balota, 2013), leading some to suggest the two paradigms measure differ processes (Aschenbrenner et al., 2017; Scaltritti & Balota, 2013). Using the whole word approach, we found a consistent pattern of fixated letter effects across both experiments, within pseudowords as well as words. We have not identified the source of the discrepancy, but since the effect is considerably weaker in the whole word paradigm, and absent still for number and consonant strings, we agree that the measured processes are not identical, but more related than previously assumed.

Interestingly, the surprise effect at the fixated letter for pseudowords was eliminated in the matching phonology condition in Experiment 1, and the fixated letter effect for words was eliminated in the non attended condition in Experiment 2. A same-different task using a similar approach saw no evidence of a phonological effect at position 3 (Kinoshita & Norris, 2009).

As seen in Experiment 2, shifting attention to the letter in position 2 improved accuracy in words and pseudowords, an improvement not seen for any other letter position, including the first. A parallel may be drawn between this finding and the second letter effect found in Winskel et al. (2018), where Thai words and nonwords with an initial phoneme in the second position had a higher accuracy compared with other letter positions. Since they also found an initial letter position effect in words and nonwords with an initial phoneme in the first position, an adaptive attentional mechanism sensitive to the initial phonological letter is likely. Similarly, the increased accuracy at position 2 found in Experiment 2 suggests that this adaptive mechanism is also amenable to English, but not without an attentional prime. Interestingly, attention to other letters does not improve the accuracy or reaction time in words or pseudowords.

Our findings of the first letter advantage are largely aligned with previous studies. We found littler evidence of a phonological advantage of the first letter position across consonants and pseudoword conditions, and stronger evidence for an effect of attention at the first position on words, but not for number strings, consonant strings, or pseudowords. Importantly, the lack of effect for nonwords is not evidence against an attentional mechanism for a first position advantage. Not only could the attentional distractor have insufficient saliency with respect to the proposed draw of the first position, but the attention between the first position and any other position could also be divided. As discussed earlier, the proposed mechanisms accounting for the first letter advantage are not necessarily mutually exclusive, and may be explained by a combination of the attentional account proposed by Aschenbrenner et al. (2017) and the MRFH.

Table 1
Posterior contrasts between letter positions for the mismatching phoneme condition. The 95% credible intervals that do not include zero are marked with an asterisk.

		Accuracy		***Reaction Time***	
Condition	**Position Contrasts**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Consonants	1 vs. 2	14.55%*	[9.15, 20.07]	-165.8*	[-238.6, -94.9]
	1 vs. 3	15.53%*	[10.19, 20.79]	-178.9*	[-253.8, -105.0]
	1 vs. 4	15.76%*	[10.34, 21.20]	-150.1*	[-221.8, -76.4]
	1 vs. 5	16.15%*	[10.63, 21.57]	-192.2*	[-268.5, -118.1]
	2 vs. 3	0.97%	[-4.72, 6.56]	-13.2	[-89.5, 64.4]
	2 vs. 4	1.19%	[-4.73, 7.03]	17.8	[-60.6, 92.7]
	2 vs. 5	1.57%	[-4.43, 7.15]	-26.3	[-104.6, 50.9]
	3 vs. 4	0.22%	[-5.42, 6.08]	29.2	[-46.2, 105.0]
	3 vs. 5	0.54%	[-5.25, 6.44]	-13.8	[-90.8, 65.5]
	4 vs. 5	0.34%	[-5.53, 6.08]	-42.8	[-117.2, 34.2]
Pseudowords	1 vs. 2	16.48%*	[11.02, 21.65]	-175.4*	[-230.2, -119.5]
	1 vs. 3	9.88%*	[4.86, 14.83]	-225.7*	[-278.6, -170.7]
	1 vs. 4	17.75%*	[12.55, 23.13]	-224.5*	[-282.2, -166.3]
	1 vs. 5	13.95%*	[8.78, 19.12]	-183.1*	[-238.2, -126.4]
	2 vs. 3	-6.49%*	[-12.00, -0.92]	-49.8	[-109.8, 9.0]
	2 vs. 4	1.34%	[-4.35, 7.07]	-49.0	[-110.1, 11.6]
	2 vs. 5	-2.49%	[-8.06, 2.97]	-7.3	[-66.1, 50.4]
	3 vs. 4	7.83%*	[2.44, 13.30]	1.3	[-59.6, 59.6]
	3 vs. 5	4.08%	[-1.43, 9.45]	42.4	[-15.1, 98.5]
	4 vs. 5	-3.81%	[-9.44, 1.59]	42.2	[-17.2, 106.3]

Table 2

Posterior contrasts between the mismatching phonology condition and the matching phonology condition for each letter position. The 95% credible intervals that do not include zero are marked with an asterisk.

		Accuracy		***Reaction Time***	
Condition	**Position Contrasts**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Consonants	1	-6.28%*	[-11.11, -1.32]	76.7*	[9.8, 140.3]
	2	-1.25%	[-6.89, 4.42]	47.9	[-30.5, 125.8]
	3	0.92%	[-4.88, 6.71]	7.3	[-72.5, 89.8]
	4	3.21%	[-2.66, 8.76]	40.6	[-32.9, 123.1]
	5	-2.12%	[-7.78, 3.64]	33.7	[-44.2, 109.3]
Pseudowords	1	4.00%	[-0.55, 8.80]	38.9	[-12.7, 94.4]
	2	3.36%	[-2.31, 8.92]	41.5	[-21.4, 102.2]
	3	9.98%*	[4.46, 15.56]	5.2	[-55.0, 64.4]
	4	1.57%	[-3.86, 7.18]	39.0	[-21.1, 99.9]
	5	6.86%*	[1.25, 12.62]	-28.2	[-89.8, 30.5]

Table 3

Posterior contrasts of letter position for the no distractor (control) condition. The 95% credible intervals that do not include zero are marked with an asterisk.

		Accuracy		***Reaction Time***	
Condition	**Position Contrasts**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Numbers	1 vs. 2	13.70%*	[6.32, 21.06]	-141.5*	[-215.9, -70.6]
	1 vs. 3	20.31%*	[12.66, 28.15]	-201.0*	[-276.0, -123.2]
	1 vs. 4	28.62%*	[20.74, 35.97]	-242.5*	[-322.7, -161.2]
	1 vs. 5	24.22%*	[16.48, 31.57]	-304.5*	[-383.5, -228.7]
	2 vs. 3	6.72%	[-1.68, 15.01]	-58.4	[-134.9, 17.5]]
	2 vs. 4	14.97%*	[6.70, 23.06]	-98.5*	[-181.2, -17.2]
	2 vs. 5	10.57%*	[2.47, 18.49]	-162.7*	[-242.3, -82.3]
	3 vs. 4	8.37%	[-0.28, 16.70]	-40.8	[-128.5, 45.4]
	3 vs. 5	3.79%	[-4.76, 12.10]	-103.8*	[-188.3, -20.6]
	4 vs. 5	-4.46%	[-12.84, 3.80]	-64.1	[-148.0, 24.0]
Consonants	1 vs. 2	7.43%	[-0.92, 15.78]	-237.5*	[-312.9, -158.9]
	1 vs. 3	6.79%	[-1.05, 14.94]	-263.5*	[-340.4, -186.7]
	1 vs. 4	13.33%*	[5.20, 21.43]	-333.8*	[-413.8, -255.4]
	1 vs. 5	15.55%*	[7.47, 23.86]	-321.1*	[-403.0, -241.4]
	2 vs. 3	-0.65%	[-8.62, 7.33]	-26.1	[-106.0, 55.4]
	2 vs. 4	5.89%	[-2.54, 14.09]	-96.9*	[-178.6, -14.9]
	2 vs. 5	8.11%	[-0.24, 16.36]	-83.7*	[-166.3, -1.0]
	3 vs. 4	6.48%	[-1.85, 14.53]	-71.2	[-152.4, 8.8]
	3 vs. 5	8.70%*	[0.52, 16.85]	-58.7	[-136.9, 21.1]
	4 vs. 5	2.31%	[-6.09, 10.55]	12.8	[-73.0, 99.7]
Pseudowords	1 vs. 2	5.79%	[-0.90, 12.52]	-221.4*	[-284.4, -160.6]
	1 vs. 3	5.81%	[-1.20, 12.71]	-148.7*	[-211.9, -86.2]
	1 vs. 4	10.84%*	[4.13, 17.94]	-204.6*	[-266.6, -142.3]
	1 vs. 5	6.78%*	[0.16, 13.59]	-234.9*	[-296.9, -173.1]
	2 vs. 3	-0.01%	[-7.40, 7.21]	72.5*	[10.6, 137.4]
	2 vs. 4	5.14%	[-2.23, 12.26]	16.6	[-44.7, 79.2]
	2 vs. 5	1.02%	[-5.98, 8.22]	-13.6	[-76.9, 49.6]
	3 vs. 4	5.14%	[-2.19, 12.45]	-54.9	[-116.9, 6.6]
	3 vs. 5	1.09%	[-6.13, 8.17]	-86.2*	[-145.4, -21.6]
	4 vs. 5	-4.03%	[-11.14, 2.97]	-30.2	[-92.8, 30.4]
Words	1 vs. 2	9.20%*	[4.28, 14.78]	-189.1*	[-242.5, -130.3]
	1 vs. 3	6.87%*	[2.00, 12.34]	-215.6*	[-272.6, -159.2]
	1 vs. 4	13.35%*	[7.87, 19.47]	-216.1*	[-273.5, -159.3]
	1 vs. 5	15.88%*	[10.09, 22.20]	-173.2*	[-233.7, -118.5]
	2 vs. 3	-2.34%	[-8.34, 3.49]	-27.0	[-85.5, 32.0]
	2 vs. 4	4.06%	[-2.14, 10.87]	-27.7	[-85.4, 32.7]
	2 vs. 5	6.61%*	[0.34, 13.18]	13.7	[-46.1, 72.1]
	3 vs. 4	6.44%	[-0.07, 12.78]	-0.8	[-60.0, 57.5]
	3 vs. 5	8.96%*	[2.52, 15.49]	40.5	[-19.9, 100.0]
	4 vs. 5	2.47%	[-4.09, 9.37]	41.4	[-17.9, 101.1]

Table 4

Posterior contrasts between the no distractor (control) condition and the non attended condition. The 95% credible intervals that do not include zero are marked with an asterisk.

		Accuracy		***Reaction Time***	
Condition	**Position Contrasts**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Numbers	1	4.54%	[-1.15, 9.67]	-133.1*	[-190.8, -75.0]
	2	-0.79%	[-7.15, 5.66]	-100.7*	[-158.8, -39.3]
	3	-0.52%	[-7.71, 6.17]	-86.3*	[-152.3, -24.9]
	4	-6.68%	[-13.28, 0.16]	-129.8*	[-199.1, -58.3]
	5	0.46%	[-6.16, 7.17]	-30.6	[-96.2, 36.7]
Consonants	1	-3.19%	[-9.26, 3.00]	-93.4*	[-152.7, -34.2]
	2	1.85%	[-4.96, 8.36]	-62.4	[-125.3, 1.7]
	3	2.35%	[-4.10, 8.52]	-86.6*	[-149.8, -25.7]
	4	0.87%	[-5.62, 7.30]	0.1	[-66.9, 67.8]
	5	-0.98%	[-7.49, 5.49]	-43.5	[-110.0, 23.6]
Pseudowords	1	1.07%	[-4.46, 5.94]	-64.7*	[-113.1, -16.9]
	2	3.54%	[-1.95, 9.17]	22.3	[-27.6, 69.1]
	3	9.88%*	[3.91, 15.69]	-106.0*	[-155.6, -56.9]
	4	3.86%	[-2.39, 9.56]	-40.8	[-92.6, 7.6]
	5	8.89%*	[3.13, 14.59]	-13.4	[-63.6, 36.5]
Words	1	6.08%*	[2.33, 9.82]	-113.7*	[-158.4, -70.2]
	2	0.81%	[-4.40, 5.43]	-40.3	[-87.3, 5.6]
	3	5.88%*	[0.72, 10.43]	-37.1	[-82.6, 9.5]
	4	0.98%	[-4.45, 6.26]	-28.5	[-74.8, 19.4]
	5	1.11%	[-4.41, 6.48]	-57.9*	[-105.1, -8.8]

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