Children and Adults Both See “Pirates” in “Parties”:
Letter-Position Effects for Developing Readers and Skilled Adult Readers

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ABSTRACT

Developing readers often make anagrammatical errors (e.g., misreading *pirates* as *parties*) suggesting they use letter position flexibly during word recognition. However, while it is widely assumed that the occurrence of these errors decreases with increases in reading skill, empirical evidence to support this distinction is lacking. Accordingly, we compared the performance of developing child readers (aged 8-10 years) against the end-state performance of skilled adult readers in a timed naming task, employing anagrams used previously in this area of research. Moreover, to explore the use of letter position by developing readers and skilled adult readers more fully, we used anagrams which, to form another word, required letter transpositions over only interior letter positions, or both interior and exterior letter positions. The patterns of effects across these two anagram types for the two groups of readers were very similar. In particular, both groups showed similarly-slowed response times (and developing readers increased errors) for anagrams requiring only interior letter transpositions but not for anagrams that required exterior letter transpositions. This similarity in the naming performance of developing readers and skilled adult readers suggests that the end-state skilled use of letter position is established earlier during reading development than is widely assumed.

199 words

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Current models of learning to read (e.g., Grainger, Lété, Bertrand, Dufau, & Ziegler, 2012; see also Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) postulate that, having mastered rules of spelling-to-sound translations, readers must develop orthographic representations that map the printed word onto its meaning. A central assumption of these models is that these orthographic representations are coarse-coded early in reading development, so that the identities and positions of letters in words are only approximate, and are refined as the reader's vocabulary grows. Indeed, an influential account of this process (the lexical tuning hypothesis; Castles, Davis, Cavelot, & Forster, 2007; Castles, Davis, & Lechter, 1999; see also Lété & Fayol, 2013) proposes that the specification of letter position follows a developmental trajectory from less precise to more precise as the vocabulary grows and orthographic representations must become more finely tuned to discriminate between words.

Support for this view comes mainly from studies that have investigated the processing of pseudowords created by transposing letters in real words (e.g., *cholocate* is a pseudoword derived from *chocolate*). For instance, some studies have shown that brief displays of these transposed-letter pseudowords facilitate recognition of the original word more for developing child readers than for skilled adult readers (Castles et al., 2007; Lété & Fayol, 2013; but see Acha & Perea, 2008). Developing readers are also more likely to categorize transposed-letter pseudowords as real words (Grainger et al., 2012) and to read aloud these pseudowords as the words from which they were derived (Perea & Estevez, 2008). Based on these findings, it is often argued that developing readers process letter position less precisely than skilled adult readers. However, if imprecision in the use of letter position is a general feature of the developing word recognition system, effects of flexibility in the use of letter position observed so far for pseudowords also should be observed for real words and this would serve as a key indication of its natural role in word recognition. Indeed, developing readers may

have particular difficulty processing anagrams, such as *pirates*, which can form another word (i.e., *parties*) by transposition of their component letters¹. Consequently, an assessment of the processing of appropriate anagrams should provide particularly valuable insight into use of letter position when words are recognized by developing readers.

Evidence of difficulty in reading anagrams has been found in studies of children with letter position dyslexia who often make anagrammatical errors (*pirates* read as *parties*; Friedmann & Rahamim, 2007; Kohnen, Nickels, Castles, Friedmann, & McArthur, 2012). However, most recently, Kohnen and Castles (2013) showed that typically developing readers aged between 7 and 10 years also make these anagrammatical errors, suggesting that letter transposition may be an important characteristic of the word recognition performance of typically developing readers. The same study also found little variation in the proportion of anagrammatical errors across the age range and so no indication of developmental change in the usefulness of letter position. However, the focus of the Kohnen and Castle's study was wholly on the performance of children, and so it remains to be established if the role of letter position for developing readers differs relative to the final-state performance of skilled adults.

Indeed, a wealth of evidence indicates that skilled adult readers experience surprisingly little difficulty when the order of letters in words is jumbled, so long as the exterior letters (the beginning and end letters of words) remain in their original locations (e.g., Andrews, 1996; Andrews & Lo, 2012; Chambers, 1979; Forster, Davis, Schoknecht, & Carter, 1987; Johnson & Eisler, 2012; Johnson, Rayner, & Perea, 2007; Perea & Lupker, 2003; Rayner, White, Johnson, & Liversedge, 2006; White, Johnson, Liversedge, & Rayner, 2008; see also Jordan, 1990, 1995; Jordan, Patching & Thomas, 2003; Jordan, Thomas, & Patching, 2003; Jordan, Thomas, Patching, & Scott-Brown, 2003; Jordan, Thomas, & Scott-Brown, 1999). These findings are widely interpreted as showing that letter position is used flexibly even for skilled adult word recognition (e.g., Davis, 2010; Gómez, Ratcliff & Perea,

2008; Norris & Kinoshita, 2012). However, it remains to be determined if skilled adult readers make flexible use of letter position when processing anagrams and so it is currently unclear how this performance with words contrasts with that of developing readers.

Accordingly, the central aim of the present research is to cast more light on the developmental trajectory of the influence of letter position on word recognition by comparing the performance of typically developing readers with that of skilled adult readers when processing anagrams.

But when addressing this matter, it also is important to consider the locations of the letters across which transpositions may occur. In particular, previous research with skilled adult readers indicates that exterior letters in words play a privileged role in word recognition (e.g., Humphreys, Evett, & Quinlan, 1990; Humphreys, Evett, Quinlan, & Besner, 1987; Jordan, 1990, 1995; Jordan, Patching & Thomas, 2003; Jordan, Thomas, & Patching, 2003; Jordan, Thomas, et al., 2003; Jordan et al., 1999) and this is consistent with the finding that skilled adult reading is disrupted more by the transposition of exterior letters than interior letters (e.g., White et al., 2008). Other research on reading development shows that exterior letters also play an important role in learning spelling-to-sound translations (e.g., Ehri & Wilce, 1985; Rack, Hulme, Snowling, & Wightman, 1994; Stuart & Coltheart, 1988). However, the role of exterior letters in the recognition of words after developing readers have mastered the rules of spelling-to-sound translation currently is unclear although, in line with the lexical tuning hypothesis (e.g., Castles et al., 1999, 2007), it may be the case that the privileged role of these letters in skilled reading exhibits a developmental trajectory.

Indeed, the study by Kohnen and Castles (2013) examined performance for anagrams requiring transpositions over only interior letters to form another word and those requiring transpositions over both interior and exterior letters, but found little difference in error rates between these two conditions for developing readers. These findings suggest that developing

readers assign no special importance to the exterior letters of words when reading anagrams although this important issue merits further investigation. Moreover, inflexibility in the use of exterior letter position is a fundamental feature of skilled word recognition and an important hallmark of current models of word recognition (e.g., Davis, 2010; Gómez et al., 2008; Grainger & van Heuven, 2003; Whitney, 2001), and so understanding the influence of interior and exterior letter positions on word recognition by developing and skilled readers will cast light on developmental change in the use of letter position information for word recognition. Consequently, in order to more fully explore the use of interior and exterior letter positions by developing readers and skilled adult readers, we used anagrams that differed in the locations over which transpositions to form other words needed to occur.

When investigating these issues, it is important to consider the methodology employed. Research in this area often uses naming tasks in which participants are required to read words aloud and a record is made of errors in which the presented word is misread as another word. Indeed, previous investigations of anagram processing have relied exclusively on measures of error rates (Friedmann & Rahamim, 2007; Kohnen & Castles, 2013; Kohnen et al., 2012). Although this approach has the advantage of revealing the nature of the errors made, it is common for studies to also assess the time taken to begin saying a word, and this provides a particularly sensitive indication of the processes underlying word naming (e.g., de Jong, & Messbauer, 2011; Perea & Estevez, 2008; Spinelli, De Luca, Di Filippo, Mancini, Martelli, & Zoccolotti, 2005).

Accordingly, the present experiment used a naming task in which error rates and response times were both assessed, and performance for words that are anagrams was compared against that for words that are not anagrams (and so could not form another word by letter transposition). The logic of this approach is that if letter position is used flexibly, the presentation of an anagram will strongly activate lexical representations both for the

presented word and its anagrammatical counterparts, and this will interfere with the processing of the presented word. Moreover, to explore this influence of letter position more fully, we used two types of anagram that differed in the locations over which transpositions may occur. In particular, one type of anagram could form another word by the transposition of letters at only interior positions (e.g., *bread*, *beard*), whereas the other type of anagram always required the transposition of letters at both interior and exterior-final letter positions to form another word (e.g., *begin*, *being*). The logic of this approach was that, at least for skilled adult readers, the exterior letters of anagrams may be less transposable than interior letters, and this may reflect the importance of exterior letters in skilled word recognition (as previous evidence using other approaches suggests; e.g., Humphreys et al., 1987, 1990; Jordan, 1990, 1995; Jordan, Patching & Thomas, 2003; Jordan, Thomas, & Patching, 2003; Jordan, Thomas, et al., 2003). Accordingly, anagrams that require the transposition of exterior letters to form another word may strongly activate the lexical representation of the presented word but not its anagrammatical counterparts. Consequently, word naming difficulty may be more likely to be produced for those anagrams that can form another word by the transposition of letters exclusively at interior locations than for anagrams that also require the transposition of an exterior letter.

From previous research (Lété & Fayol, 2013), word naming generally is slower and more error-prone for developing readers than skilled adult readers, and so developing readers in the present study should generally respond more slowly and make more errors than skilled adult readers. However, if the use of letter position for reading is less precise for developing readers than for skilled adult readers, as the lexical tuning hypothesis predicts, developing readers should show greater word naming difficulty than skilled adult readers for anagrams compared to non-anagrams. In contrast, if the use of letter position is already fully established for developing readers, both groups of readers should show similar differences in

performance for anagrams compared to non-anagrams. Moreover, if skilled readers have greater difficulty for anagrams that can form another word by the transposition of letters exclusively at interior locations compared to anagrams that also require the transposition of exterior letters, this pattern should also be revealed in the present experiment. Indeed, and more importantly, if developing readers and skilled adult readers share the same usage of letter position, this pattern of effects should be observed for both groups of readers.

METHOD

Participants. Participants were 28 developing readers (8-10 years, $M = 9.2$ years, $sd = .7$ years [6 8-year-olds, 11 9-year-olds, and 11 10-year-olds]) from a primary school in Leicester and 28 skilled adult readers (18-30 years) from the local Leicester community. Participants had normal or corrected-to-normal vision. Standard reading tests (for developing readers, a revised Burt Word Reading Test, Burt, 1974, and for skilled adult readers, the Nelson-Denny Reading Test, Brown, Fishco & Hanna, 1993) were used to screen the reading abilities of developing readers and skilled adult readers, and all participants showed reading ability appropriate to their age group. For the child participants, the Burt Word Reading Test provides an approximate Equivalent Age Band for performance. Scores ranged between 8.00 and 11.04 years ($M = 9.06$ -10.00 years).

Design and Stimuli. Stimuli were 160, 4-7 letter words selected from the Children's Printed Word Database (Masterson, Stuart, Dixon, & Lovejoy, 2010) and included words used in previous research in this area (Kohnen & Castles, 2013). The listing of these words in the Children's Printed Word Database indicates that these words should be known to child readers in primary education. These words comprised 20 pairs of anagrams that could form another word by transposition of letters at exclusively interior positions (interior anagrams, e.g., *bread*, *beard*), and 20 pairs that require the transposition of letters at both interior and an exterior position (i.e., the final letter in the word) to form another word (interior/exterior

anagrams, e.g., *begin*, *being*). These two sets of anagrams were closely matched for the mean number of other words that could be formed by transposition of their component letters (interior anagrams = 1.9 words, interior/exterior anagrams = 1.8 words). In addition, the two sets of anagrams were each matched separately with a set of non-anagram control words for length (interior anagrams = 5.2 letters, matched non-anagrams = 5.2 letters; interior/exterior anagrams = 4.3 letters, matched non-anagrams = 4.3 letters) and absolute word frequency, obtained from the Children's Printed Word Database (interior anagrams = 99.3 counts/million, matched non-anagrams = 99.2 counts/million; interior/exterior anagrams = 55.7 counts/million, matched non-anagrams = 55.7 counts/million)².

Orthographic neighbors (i.e., the number of words that can be created by substituting one letter for another while preserving letter position and length, e.g., Coltheart, Davelaar, Jonasson, & Besner, 1977) have also been shown to influence the recognition of words (see, e.g., Andrews, 1997). In addition, a word's phonological neighbors (i.e., words created by substituting one phoneme for another while preserving word length and phoneme order) have been shown to influence word naming in particular (e.g., Ziegler, Muneaux, & Grainger, 2003). Therefore, we also calculated the number of orthographic and phonological neighbors for each word (using the N-Watch program; Davis, 2005). The number of neighbors was closely matched for interior anagrams (orthographic N = 4.9, phonological N = 11.6) and their control words (orthographic N = 4.9, phonological N = 10.4), but it proved difficult given other constraints on stimulus generation and the vagaries of the English language to match interior/exterior anagrams (orthographic N = 9.6, phonological N = 16.0) and their control words (orthographic N = 5.7, phonological N = 11.5) so closely. Therefore, the influence of these neighborhood differences was taken into account in this study by including the number of orthographic and phonological neighbors for each word as additional factors in the statistical model.

Apparatus and Procedure. Participants were tested individually. Stimuli were presented in lower-case 18-point Arial font as black text on a white background on a high definition screen using E-Prime 2.0 (Psychology Software Tools, Inc., www.pstnet.com). Participants were seated at a normal viewing distance of approximately 50 cm from the screen. Stimulus displays were presented in random order in a single session, preceded by a practice session containing 20 words. At the start of each trial, a fixation cross was displayed at the center of the screen for 500ms before being replaced by a stimulus. Each stimulus was displayed for 3s and there was a 500ms interval before the next trial. Participants were instructed to read each stimulus aloud as quickly and accurately as possible into a microphone interfaced with a serial response box which provided millisecond accuracy. Response times and errors were recorded. The timing of response times began at the onset of each stimulus. Errors in which words were incorrectly named were recorded.

RESULTS

Response times and error rates are shown in Figure 1. Response times were analyzed using a linear mixed effects model (Baayen, Davidson, & Bates, 2008) and error data were analyzed using a logistic mixed-effects model (Jaeger, 2008) using R (R Development Core Team, 2010). This approach has advantages over other approaches based on more traditional Analyses of Variance by simultaneously taking account of the separate sources of error variance associated with participants and stimuli in the same model (for further discussion, see Baayen, 2008). Both models specified participants and stimuli as crossed random effects. Fixed factors were reading skill (developing readers, skilled adult readers), word type (anagram, non-anagram) and type of transposition (interior, interior/exterior). Response times for words named incorrectly were excluded from the analysis of response times, as were latencies under 250 ms or over 2000 ms, following prior research (e.g., Perea & Estevez, 2008). This accounted for 15.5% of all data. The patterns of effects were identical

for models computed using log-transformed and untransformed response times, and so findings are reported for the untransformed data. Analyses that included the numbers of orthographic and phonological neighbours for each word as additional factors produced the same pattern of effects as analyses that omitted these variables, and so analyses are reported that do not include these variables. In addition, analyses that included the order in which each member of an anagram pair was presented to each participant as a fixed factor showed the same pattern as analyses that omitted this variable, and so the reported analyses also exclude this variable.³ *P*-values for the response time data were estimated using posterior distributions for model parameters obtained by Markov chain Monte Carlo sampling (Baayen et al., 2008).

-----Figure 1-----

For response times, there was a main effect of reading skill ($b = 83.68$, $SE = 35.52$, $t = 2.36$, $p < .05$), due to slower responses by developing readers than skilled adult readers. Main effects of word type ($b = -39.66$, $SE = 10.42$, $t = 3.81$, $p < .001$) and type of transposition ($b = -36.05$, $SE = 11.31$, $t = 3.19$, $p < .01$) were qualified by an interaction of these factors ($b = 35.63$, $SE = 13.29$, $t = 2.68$, $p < .01$) but no significant 3-way interaction of these factors with reading skill ($b = -11.60$, $SE = 14.49$, $t = .80$, $p < .50$), and no other significant effects ($bs < 17$, $ts < 1.7$, $ps < .15$). The interaction between word type and type of transposition showed that responses were slower (relative to non-anagram control words) for interior anagrams but not interior/exterior anagrams (which required the transposition both of interior letters and the final letter of each word), and this pattern of response times was the same for developing readers and skilled adult readers.

Skilled adult readers made very few errors (only 4%) and only for interior anagrams, and so error data for these readers violated assumptions of homoscedasticity (see, e.g., Quené & van den Bergh, 2008). Nevertheless, an analysis that included these data confirmed that

skilled adult readers made fewer errors than developing readers ($b = 1.68$, $SE = .33$, $z = 4.97$, $p < .001$). An analysis of the error rates was not informative about effects of letter position for skilled adult readers due to lack of homoscedasticity, but an analysis of error rates for only the developing readers produced main effects of word type ($b = 1.81$, $SE = .32$, $z = 5.57$, $p < .001$), and type of transposition ($b = 1.32$, $SE = .34$, $z = 3.87$, $p < .001$), and an interaction of these factors ($b = 1.34$, $SE = .43$, $z = 3.14$, $p < .01$). This interaction was due to increased errors (relative to non-anagram control words) for interior anagrams (17% vs. 4%) but not for interior/exterior anagrams (6% vs. 4%), and so indicates that error rates for developing readers differed for these two types of anagram.

DISCUSSION

The experiment reported in this study is the first to use a timed naming task to investigate anagram processing by typically developing readers and skilled adult readers. Developing readers responded generally more slowly and made generally more errors than skilled adult readers, and this is consistent with findings from previous research showing that word naming typically is slower and more error-prone for developing readers than skilled adult readers (e.g., Lété & Fayol, 2013). In the present study, developing readers also made a similar number of errors for anagrams (mean = 12%) as reported in previous research with developing readers from a similar age group (mean = 14% in the study by Kohnen & Castles, 2013). The general performance of the developing readers in the present research was therefore matched very closely to that reported previously for developing readers in this area.

Response times in the present study corresponded to the time taken to begin articulating a word after stimulus onset and this approach provides a particularly sensitive measure of word naming difficulty. For both groups of readers, response times (relative to control words) were longer for interior anagrams (which could form another word only by transposition of their interior letters) but not interior/exterior anagrams (which required the

transposition of both interior letters and the end letter of the word to form another word). The indication, therefore, is that flexibility in the use of letter position produced word naming difficulty for both groups of readers only for anagrams that required the transposition of letters exclusively at interior locations to form another word. Indeed, the implication of these findings is that, for both groups of readers, presentation of this type of anagram strongly activates lexical representations for both for the presented word and its anagrammatical counterparts, and these multiple activations interfered with processing of the presented word.

By comparison, the apparent lesser difficulty for naming interior/exterior anagrams suggests that both groups showed sensitivity to the privileged role of exterior letters for word recognition previously established for skilled adult readers (e.g., Humphreys et al., 1987, 1990; Jordan, 1990, 1995; Jordan, Patching & Thomas, 2003; Jordan, Thomas, & Patching, 2003; Jordan, Thomas, et al., 2003; Jordan et al., 1999). Accordingly, this pattern of effects suggests that presentation of an interior/exterior anagram activates the lexical representation for the presented word but not its anagrammatical counterparts, and so causes little interference to the processing of the presented word, for both skilled and developing readers. Indeed, the very similar patterns of effects for both sets of readers are especially important as they underscore the notion that developing and skilled adult readers have the same flexibility in their use of letter position. Consequently, these findings for anagram reading show for the first time that end-state skilled sensitivity to letter position, and the privileged status of the exterior letters in words, is well-established in developing readers.

Developing readers also produced increased errors (relative to matched control words) for interior anagrams but not interior/exterior anagrams. These findings concord with the reaction time findings and add further support to the view that interior but not interior/exterior anagrams are confusable with their anagrammatical counterparts. However, the present findings contrast with those of Kohnen and Castles (2013) which showed little

difference in the errors rates for interior anagrams and interior/exterior anagrams. However, this variation between these two findings may be a consequence of the smaller number of interior/exterior anagrams used by Kohnen and Castles (only 16 from a total of 60 anagrams) compared to the present study (40 from a total of 80 anagrams). The pattern of errors in the present research therefore adds to the response time findings to provide a substantial and novel indication of developing readers' use of letter position.

By comparison with developing readers, skilled adult readers in the present research made very few errors at all, suggesting that they can inhibit a prepotent inappropriate naming response more proficiently than developing readers. This may reflect the superior word processing abilities of skilled adult readers or the generally greater maturation of their cognitive abilities. Indeed, extensive evidence reveals developmental differences in executive control (see, e.g., Best & Miller, 2010) which may enhance an individual's ability to inhibit inappropriate verbal responses as they reach maturity. This developmental difference is of considerable concern for studies that compare only error rates in word naming across age groups, since such studies cannot provide a complete indication of developmental differences in performance. Accordingly, the special focus of the present research to include response times as well as error rates to determine the use of letter position by developing and skilled readers has considerable merit.

The present findings also contrast with evidence for developmental differences in the use of letter position in previous research that used pseudoword stimuli created by transposing letters in real words (e.g., *cholocate* / *chocolate*). In this previous research, brief presentations of transposed-letter pseudowords primed recognition of the original words more for developing readers than skilled adult readers (Castles et al., 2007; Lété & Fayol, 2013). Moreover, developing readers were more likely than skilled adult readers to incorrectly categorize transposed-letter pseudowords as real words (Grainger et al., 2012), and to

misread these pseudowords as real words (Perea & Estevez, 2008). However, the present findings indicate that the greater flexibility in the use of letter position by developing readers than skilled adult readers for pseudowords in this previous research is not also observed for real words, and so may not be a general feature of the developing word recognition system. Indeed, it has been argued that developing readers are more likely than skilled adult readers to assign a valid and orthographically similar lexical entry to a pseudoword (see Ehri, 2005; Seymour & Elder, 1986), and so this more flexible use of letter position by developing readers may be specific to situations where no real word candidate exists.

The similarity in use of letter position by developing and skilled adult readers in the present research runs contrary to the lexical tuning hypothesis (Castles et al., 2007; Castles et al., 1999; see also Grainger et al., 2012), and challenges the view that there is a developmental trajectory in the specification of letter position. Indeed, the very clear indication from the present research is that the use of letter position by developing readers is very similar to end-state adult performance. In addition, the developing readers in the present research were from a similar age range as developing readers in previous developmental research in this area (Castles et al., 2007; Lt & Fayol, 2013; Perea & Estevez, 2008), and produced error rates comparable with those observed in previous research on anagram processing (Kohnen & Castles, 2013). Consequently, the pattern of performance observed in the present research is likely to be typical of developing readers. Moreover, previous studies that have examined subsets of readers in Grades 2 to 4 (i.e., 7-10 year olds) have observed little change in the use of letter position across this age range (Acha & Perea, 2008; Castles et al., 2007; Kohnen & Castles, 2013), and so it seems unlikely that a transition in the use of letter position occurs during this crucial period for reading development. Indeed, flexibility in the use of letter position may be a pervasive characteristic of word recognition (certainly in Latinate languages, such as English) that is established early in the process of learning to read

and thereafter shows little developmental change.

Such flexibility in the use of letter position poses an important challenge to traditional models of word recognition (e.g., McClelland & Rumelhart, 1981; Coltheart et al., 2001; Grainger & Jacobs, 1996; Paap, Newsome, McDonald & Schvaneveldt, 1982) in which letter position is encoded precisely. However, it is compatible with newer models that incorporate more flexible letter-position encoding (e.g., Davis, 2010; Grainger & van Heuven, 2003; Gómez et al., 2008; Whitney, 2001; see also Grainger et al., 2012). Although the mechanisms used to encode letter positions flexibly in these newer models varies (e.g., positional uncertainty, open bigrams), the models share the assumption that interior letter positions are encoded more flexibly than exterior letter positions. The present findings do not arbitrate between the alternative mechanisms for encoding letter position described in these models but underscore the special status of exterior letter information for word recognition by both developing and skilled readers, and emphasize the importance of implementing flexibility in the encoding of letter position in developmental models of word recognition.

In sum, the present research provides a novel demonstration that the use of letter position by developing readers closely resembles that for skilled adult readers. Indeed, the present findings imply considerable stability rather than developmental change in the use of letter position in word recognition, although further work is now required to extend this work to other categories of words. Nevertheless, the indication already is that end-state skilled use of letter position, including the privileged role of exterior letters, is established early in the process of learning to read.

FOOTNOTE

1. In this article, we use the word anagram in its literal form to describe a word which can form another word by rearrangement of the order of its letters.
2. We also examined the difference in frequency between words in each anagram pair, which did not differ for interior compared to interior/exterior anagrams, $t < 1$.
3. As in previous research in this area, it was not possible to match the word stimuli for initial phonemes (see, e.g., Rastle & Davis, 2002) due to the relative rarity of anagrams. However, an LME analysis of response times which included the initial phoneme of each word as a variable produced the same pattern of findings as an analysis that did not include this variable. This indicated that the pattern of findings we obtained was not affected by variation in the initial phoneme of the word stimuli.

REFERENCES

- Acha, J., & Perea, M. (2008). The effects of length and transposed-letter similarity in lexical decision: Evidence with beginning, intermediate, and adult readers. *British Journal of Psychology*, 99, 245-264.
- Andrews, S. (1996). Lexical retrieval and selection processes: Effects of transposed-letter confusability. *Journal of Memory and Language*, 35, 775-800.
- Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review*, 4, 439-461.
- Andrews, S., & Lo, S. (2012). Not all skilled readers have cracked the orthographic code: Individual differences in masked form priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 38, 152-163.
- Baayen, H.R. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge University Press: Cambridge, UK.
- Baayen, H.R., Davidson, D.J., & Bates, D.M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59, 390-412.
- Best, J.R., & Miller, P.H. (2010). A developmental perspective on executive function. *Child Development*, 81, 1641-1660.
- Brown, J.A., Fishco, V.V., & Hanna, G. (1993). *Nelson-Denny Reading Test: Manual for Scoring and Interpretation, Forms G & H*. Rolling Meadows, IL: Riverside Publishing.
- Burt, C. (1974). *Burt Word Reading Test, 1974 Revision by Scottish Council for Research in Education*. University of Glasgow, Scotland: Hodder & Stoughton Educational.
- Castles, A., Davis, C., Cavalot, P., & Forster, K.I. (2007). Tracking the acquisition of

- orthographic skills in developing readers: Masked form priming and transposed-letter effects. *Journal of Experimental Child Psychology*, 97, 165-182.
- Castles, A., Davis, C., & Letcher, T. (1999). Neighborhood effects on masked form-priming in developing readers. *Language and Cognitive Processes*, 14, 201-224.
- Chambers, S.M. (1979). Letter and order information in lexical access. *Journal of Verbal Learning and Verbal Behavior*, 18, 225-241.
- Coltheart, M., Davelaar, E., Jonasson, J. F., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention and performance VI* (pp. 535–555). Hillsdale, NJ: Erlbaum.
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108, 204-256.
- Davis, C.J. (2005). N-Watch: A program for deriving neighbourhood size and other psycholinguistic statistics. *Behavior Research Methods*, 37, 65-70.
- Davis, C.J. (2010). The spatial coding model of visual word identification. *Psychological Review*, 117, 713-758.
- de Jong, P.F., & Messbauer, V.C. (2011). Orthographic context and the acquisition of orthographic knowledge in normal and dyslexic readers. *Dyslexia*, 17, 107-122.
- Ehri, L. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading*, 9, 167-188.
- Ehri, L.C., & Wilce, L.S. (1985). Movement into reading: Is the first stage of printed word learning visual or phonetic? *Reading Research Quarterly*, 20, 163–179.
- Forster, K.I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology*, 39, 211-251.

- Friedmann, N., & Rahamim, E. (2007). Developmental letter position dyslexia. *Journal of Neuropsychology*, 1, 201-236.
- Gómez, P., Ratcliff, R., & Perea, M. (2008). The Overlap Model: A Model of Letter Position Coding. *Psychological Review*, 115, 577-600.
- Grainger, I. J. & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, 103, 518-565.
- Grainger, J., Lété, B., Bertrand, D., Dufau, S., & Ziegler, J.C. (2012). Evidence for multiple routes in learning to read. *Cognition*, 123, 280-292.
- Grainger, I. J. & Van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *Mental lexicon: Some words to talk about words*. (pp. 1-23). Hauppauge, NY: Nova Science.
- Humphreys, G.W., Evett, L.J., & Quinlan, P.T. (1990). Orthographic processing in visual word identification. *Cognitive Psychology*, 22, 517-560.
- Humphreys, G.W., Evett, L.J., Quinlan, P.T., & Besner, D. (1987). Orthographic priming: Qualitative differences between priming from identified and unidentified primes. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 105-125). Hillsdale, NJ: Erlbaum.
- Jaeger, T.F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, 59, 434-446.
- Johnson, R.L., & Eisler, M.E. (2012). The importance of first and last letter in words during sentence reading. *Acta Psychologica*, 141, 336-351.
- Johnson, R.L., Rayner, K., & Perea, M. (2007). Transposed-letter effects in Reading: Evidence from eye movements and Parafoveal Preview. *Journal of Experimental Psychology*, 33, 209-229.
- Jordan, T.R. (1990). Presenting words without interior letters: Superiority over single letters

- and influence of postmask boundaries. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 893-909.
- Jordan, T.R. (1995). Perceiving exterior letters of words: Differential influences of letter fragment and non-letter fragment masks. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 512-530.
- Jordan, T.R., Patching, G.R., & Thomas, S.M. (2003a). Assessing the role of hemispheric specialization, serial-position processing and retinal eccentricity in lateralized word perception. *Cognitive Neuropsychology*, 20, 49-71.
- Jordan, T.R., Thomas, S.M., & Patching, G.R. (2003b). Assessing the importance of letter pairs in reading: Parafoveal processing is not the only view. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 29, 900-903.
- Jordan, T.R., Thomas, S.M., Patching, G.R., & Scott-Brown, K.C. (2003). Assessing the importance of letter pairs in initial, exterior, and interior positions in reading. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 29, 883-893.
- Jordan, T.R., Thomas, S.M., & Scott-Brown, K.C. (1999). The illusory letters phenomenon: An illustration of graphemic restoration in visual word recognition. *Perception*, 28, 1413-1416.
- Kohnen, S., & Castles, A. (2013). Pirates at parties: Letter position processing in developing readers. *Journal of Experimental Child Psychology*, 115, 91-107.
- Kohnen, S., Nickels, L., Castles, A., Friedmann, N., & McArthur, G. (2012). When 'slime' becomes 'smile': Developmental letter position dyslexia in English. *Neuropsychologia*, 50, 3681-3692.
- Lété, B., & Fayol, M. (2013). Substituted-letter and transposed-letter effects in a masked priming paradigm with French developing readers and dyslexics. *Journal of Experimental Child Psychology*, 114, 47-62.

- Masterson, J., Stuart, M., Dixon, M., & Lovejoy S. (2010). Children's printed word database: Continuities and changes over time in children's early reading vocabulary. *British Journal of Psychology*, 101, 221-242.
- McClelland, J. & Rumelhart, D. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review*, 88, 375-407.
- Norris, D., & Kinoshita, S. (2012). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review*, 119, 517-545.
- Paap, K., Newsome, S. L., McDonald, J. E. & Schvaneveldt, R. W. (1982). An activation-verification model for letter and word recognition: The word superiority effect. *Psychological Review*, 89, 573-594.
- Perea, M., & Estevez, A. (2008). Transposed-letter similarity effects in naming pseudowords: Evidence from children and adults. *European Journal of Cognitive Psychology*, 20, 33-46.
- Perea, M., & Lupker, S.J. (2003). Transposed-letter confusability effects in masked form priming. In S. Kinoshita and S. J. Lupker (Eds.), *Masked priming: State of the art* (pp. 97-120). Hove, UK: Psychology Press.
- Quené, H., & van den Bergh, H. (2008). Examples of mixed-effects modelling with crossed random effects and with binomial data. *Journal of Memory and Language*, 59, 413-425.
- Rastle, K., & Davis, M.H. (2002). On the complexities of measuring naming. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 307-314.
- R Development Core Team. (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Available from: <http://www.r-project.org>.
- Rack, J., Hulme, C., Snowling, M., & Wightman, J. (1994). The role of phonology in young

- children learning to read words: The direct-mapping hypothesis. *Journal of Experimental Child Psychology*, 57, 42-71.
- Rayner, K., White, S.J., Johnson, R.L., & Livversedge, S.P. (2006). Raeding wrods with jubmled lettres: There is a cost. *Psychological Science*, 17, 192-193.
- Seymour, P.H.K., & Elder, L. (1986). Beginning readers without phonology. *Cognitive Neuropsychology*, 3, 1-36.
- Spinelli, D., De Luca, M., Di Filippo, G., Mancini, M., Martelli, M., & Zoccolotti, P. (2005). Length effect in word naming in reading: role of reading experience and reading deficit in Italian readers. *Developmental Neuropsychology*, 27, 217-235.
- Stuart, M., & Coltheart, M. (1988). Does reading develop in a sequence of stages? *Cognition*, 30, 139-181.
- White, S.J., Johnson, R.L., Livversedge, S.P., & Rayner, K. (2008). Eye movements when reading transposed text: the importance of word beginning letters. *Journal of Experimental Psychology: Human Perception and Performance*, 34, 1261-1276.
- Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin and Review*, 8, 221-243.
- Ziegler, J.C., Muneaux, M., Grainger, J. (2003). Neighborhood effects in auditory word recognition: Phonological competition and orthographic facilitation. *Journal of Memory and Language*, 48, 779-793.

Figure Legend

Figure 1. Developing and skilled readers' response times and error rates (with standard error bars) when naming interior anagrams, interior/exterior anagrams, and non-anagrammatical control words.

Figure 1