# When is a corner like corn? Morpho-orthographic segmenting skills in children who struggle with reading

by

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Abstract

Reading proficiency is considered to be one of the most important skills in early education. Although phonological awareness is regarded as the primary area of deficit in poor readers, other factors are being identified as additional predictors of reading proficiency, such as morphological awareness. Morphological awareness is the ability to consider and manipulate the smallest units of meaning in language. Morphological awareness involves knowledge of base words, and affixes (suffixes and prefixes). To measure morphological awareness, this study used a masked priming lexical decision task, where the nature of the prime words was varied, from truly morphologically related to the target word (teacher-TEACH), to pseudo-suffixed relationships (corner-CORN). A dual-route theory of orthographic processing suggests that these two types of words are processed in different ways; The former being through coarse-grained processing, where the whole word is processed at once, and the latter being through fine-grained processing, where each letter and its location in the word is processed. This study aimed to examine the developmental changes in morphological processing in skilled and poor readers, based on the type of orthographic processing that occurs. Readers in elementary school may not be using the same strategies that adults use in visual word recognition. Good readers in grade 6 demonstrated a more advanced strategy of word recognition, wherein letter order and type of suffix modulated priming effects. Grade 6 poor readers and grade 2 good readers performed similarly in that the degree of priming was not modulated by the type of suffix used. In terms of orthographic processing, good and poor readers in grade 6 used the same strategy of fine-grained processing, whereas grade 2 readers used a coarse-grained orthographic processing strategy. This suggests that reading exposure is the driving factor in the type of orthographic processing used in word recognition for both good and poor readers.

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Reading is an essential tool for academic success and functioning in our information-oriented society. There are many factors that affect reading ability, including phonological awareness, orthography, and morphological awareness. The present study examines the developmental changes in morphological awareness in poor readers and good readers in elementary school.

## What is Morphological Awareness?

Morphological awareness is the ability to consider and manipulate the smallest units of meaning in language. Morphological awareness skills influence word reading, reading comprehension and spelling abilities (Apel, Diehm & Apel, 2013). Morphological awareness involves knowledge of base words, and affixes (suffixes and prefixes). Derivational morphemes change base words by altering their meaning or word class (*teach* to *teacher*). Morphological awareness begins to develop early in childhood, in primary grades, and strengthens in time. Children as young as in kindergarten show a basic level of morphological awareness that improves across grades, reflecting knowledge of how base words are related to their inflected and derived forms (e.g. knowing the words *farm* and *farmer* have a meaningful relationship) and of conscious knowledge of affixes; for example, first and second graders are able to recognize printed suffixes and prefixes (Apel et al., 2013). Additionally, in students from grades one through six, the most pronounced growth in morphological awareness occurs within the first three grades, but it continues to grow through grades 4-6 (Berninger, Abbott, Nagy, & Carlisle, 2010).

Morphological processing begins early in visual word recognition (Lazaro, Illera, & Sainz, 2015). In recent years there have been strong advances in measuring techniques used to assess morphological awareness and knowledge. Whereas the majority of morphological knowledge research involved verbally presented test materials, recent methodology has emerged involving testing morphological processing during reading. This methodology is a derivation of the masked priming lexical decision task.

## Masked Priming Lexical Decision Task

The masked priming lexical decision task is carried out using a computer display, which briefly presents a masked prime, a cue word that can influence lexical decision-making time, usually unnoticed by the participant, followed by a target stimulus. Participants then make a simple yes or no decision regarding whether the stimulus they see on the monitor is a real word in their native language, or not a real word (the "lexical decision"). The prime is either related or unrelated to the target. When a prime is related to the target word, response times are generally faster than when an unrelated prime is used. Word knowledge is then measured based on how accurate, and how fast the participant's decision is made. Shorter response times in making a lexical decision, with related compared to unrelated primes, are assumed to reflect facilitated access to target word identity in memory, the so-called "priming effect."

When determining a reader's morphological awareness using the masked priming lexical decision task, primes are morphologically related to the target; for example, a prime may be the word *teacher* and the target would be the word *teach*. If the response time for related prime-target pairs was shorter than the response time for unrelated target and prime pairs, then it is assumed that the morphological content of the prime had an influence on target activation in memory, and that the reader had knowledge about the morphology behind the prime and target, (for example, how *teacher* and *teach* are related), respectively.

During the lexical decision task, morphological parsing of suffixed or pseudo-suffixed (words that have a morpheme ending, but are not actually suffixed in the context of the word, for example, *corner*) prime words is assumed to occur. In adults, morphologically related primes speed up lexical decisions, with pseudo-suffixed prime words (*corner-CORN*). Morphologically related primes also speed up lexical decisions in regular morphological conditions (*singer-SING*). In strict-orthographic control conditions (where the form properties of the prime and target are similar, the prime and target are semantically unrelated, and there is a non-suffix ending in the prime, e.g., *spinach-SPIN*) there is no priming effect. There is also no priming in strictly semantic control conditions, in which the prime and target are only related by meaning, (*tulip-FLOWER*) (Quémart, Casalis & Cole, 2011). The fact that morphologically related primes and pseudo-suffixed primes speed up lexical decisions demonstrates **morpho-orthographic segmenting**, wherein written words are automatically parsed, or broken down, into morphemes, independent of the actual morphological structure of the word (Beyersmann, Casalis, Ziegler & Grainger, 2015). Printed words that look similar to morphemes are parsed regardless of whether the stimuli are semantically related to the stem, suggesting an orthographic relationship (Rastle & Davis, 2008). Morpho-orthographic segmenting is important in reading acquisition because it allows readers to not only recognize words quickly, for fluent reading, but also helps them attach meaning to the words, using suffixes to guide their comprehension.

## The Dual-Route Model of Orthographic Processing

Grainger and Ziegler (2011) have proposed a dual route model of orthographic processing to explain morpho-orthographic segmentation. The goal of this model is to account for how the reader enhances the gathering of information from words that are printed, in order to get the necessary semantic information for comprehension. The two routes in the dual route model involve two different types of orthographic processing, because they are meant to use frequency of occurrence in opposite ways. The difference between the two routes is in the level of precision with which letter position information is coded. In the first route, involving coarse-grained orthographic processing, the orthographic code is computed for the purpose of quickly focusing in on a unique word identity and its corresponding semantic representations. Essentially, the strategy for this route is to code for combinations of the most visible letters that will best restrict the identity of the word. This is meant to give a fast, bottom-up, activation of whole-word representations that can be merged with context restrictions, such as the surrounding words in a sentence, to focus in on the correct meaning of the word during reading comprehension. Evidence for coarse orthographic coding in morphological awareness has been demonstrated using masked priming tasks, where there are significant priming effects with transposed-letter primes across morpheme boundaries (i.e. teacehr would activate the suffix ‘er’ for teacher; Beyersmann, Mccormick & Rastle, 2013).

The second route of the dual route model of orthographic processing involves fine-grained orthographic coding. This gives more precise information about the letter order in a string of letters. The fine-grained code lets readers code multi-letter graphemes and their specific order in a string of letters. From here, the graphemes activate the corresponding phonemes, which lead to the activation of the correct whole-word phonological representation and corresponding semantic representation (Grainger & Ziegler, 2011). It is also hypothesized that the fine-grained orthographic processing route is generally used to precisely determine the position of letters in a string, so that one can chunk the frequently occurring letter combinations, such as complex graphemes (e.g., th, ch) and small morphemes (i.e., affixes such as RE, ED, ER). This lets the orthographic information link with pre-existing sub-lexical phonological and morphological representations (Grainger & Ziegler, 2011). It has been demonstrated using transposed-letter lexical decision tasks, which are associated with coarse-grained processing, that there is a small increase in size of transposed letter priming effects from grade 1 to grade 2, and then the effects remain relatively stable until grade 4, when the priming effects decrease in size (Grainger, Lété, Bertand, Dufau & Ziegler, 2012). This suggests that coarse-grained processing is learned first, and then as readers become more efficient, the fine-grained route emerges.

In accordance with the dual route theory of orthographic processing, Diependaele and colleagues (2009) suggested that morpho-orthographic segmentation requires a fine-grained orthographic code that is sensitive to letter order. Morpho-semantic representations are hypothesized to be accessed more quickly though coarse-grained orthographic code, which is less sensitive to letter order (Diependaele et al., 2013). Taken together, the core of the dual-route model applied to morphological processing is that there are two separate mechanisms for learning to put letters together. These two mechanisms work independently of each other. When both are activated simultaneously, such as in a morphological prime condition, where the target and prime words are semantically related (*teacher-TEACH*), the coarse-grained route takes precedence, repressing the use of the fine-grained orthographic route. The mechanism for morpho-semantic processing learns that the letter F occurring somewhere before R is a good indication that the whole-word being processed is “farm” or “farmer”. The other mechanism, for morpho-orthographic segmentation recognizes that there is an E just before a final R and that this letter combination has a specific function in language (Diependaele et al., 2009). Fine grained orthographic processing such as this, enables morpho-orthographic segmentation through detecting affixes such as “er” in the word “farmer” (Grainger & Ziegler, 2011).

Using this logic, Grainger & Ziegler predicted that priming effects that are determined by morpho-orthographic processing should be impaired by manipulations that affect fine-grained orthographic processing. To examine this further, studies using letter transpositions have compared morphological primes (*farmer-farm*) with pseudo-suffixed primes (*corner-corn*), by transposing two letters across the morpheme boundaries (*faremr-farm*; *corenr-corn*). These priming effects were compared to a letter substitution control prime condition (*farivr-farm; corivr-corn*). Results demonstrated significant priming from morphological intact primes (*farmer-farm*) and morphological transposed-letter (TL) primes (*faremr-farm*), and also significant priming from intact pseudo- primes (*corner-corn*). Importantly, there was no priming from TL pseudo-derived primes (*corenr-corn*). The dual route model suggests that letter transpositions interfere with fine-grained orthographic processing, and subsequently disrupt sub-lexical morpho-orthographic segmentation. This is suggested to be the only source of priming for pseudo-derived relations (*corner-corn*), and due to this, a TL manipulation eliminates priming in this condition. Conversely, true morphological relations (*farmer-farm*) benefit from morpho-semantic priming, through coarse-grained coding. For example, *faremr* strongly activates the whole-word orthographic representation for the word *farm* through shared morpho-semantic representations (Grainger & Ziegler, 2011).

**Morphological versus Pseudo-suffixed Words with Letter Transpositions**

Diependaele and colleagues (2013) demonstrated that letter transpositions in primes disrupt morpho-orthographic processing more than morpho-semantic processing. Morpho-orthographic segmentation requires precise letter order, to separate the suffix (“er”) as an example, from the non-suffix word ending “re”. Because of this, transposing two letters across the morpheme boundary in a derived prime (e.g., worekr, corenr) should disrupt morpho-orthographic segmentation more than morpho-semantic (Diependaele et al., 2013).

The beginning of morpho-orthographic segmentation is affix stripping. In order to get successful affix stripping, individuals must have precise information about position of letters. Affixes contain few letters, and due to this, it is imperative that letter order is known, for the affix representation to be activated. For example, the “re” in store, will not provide bottom up support for the affix “er”. Because of this, letter order is essential for morpho-orthographic segmentation (Diependaele et al., 2013).

Morpho-orthographic segmentation is the only way to get priming from pseudo-suffixed words (*corner-corn*), so any change to the letters of the affix should interfere with priming, disrupting the process. However, according to the dual-route model, truly morphological primes (where the prime and target share meaning, *teacher-teach*) can facilitate word recognition through morpho-orthographic segmentation AND through whole word representation and supra-lexical morpho-semantics (where lexical representations map onto another level, where they are coded for similarity in form and meaning between known words). This means that the priming effects for morphological primes would be less affected by letter order, and letter transpositions in the affix, because there is still bottom up support for the whole word representation of the prime. Therefore, transposed letter priming effects should be evident with morphological primes when more coarse-grained processing is used, but markedly less evident for pseudo-suffixed primes (*corner-corn*), where only fine-grained analysis is used (Diependaele et al., 2013).

In Diependaele and colleagues’ study, the researchers manipulated items by transposing or replacing the last letter of the stem and the first letter of the suffix to produce either transposed letter or replaced letter primes. It was predicted that letter transpositions would affect morpho-orthographic processing more than morpho-semantic processing. The results demonstrated that morphological primes with letter transpositions facilitated the recognition of stem targets compared with replaced letter control primes, and this did not facilitate the stem targets with pseudo-suffixed primes (Diependaele et al., 2013).

Letter transpositions affected morphological priming in the morphological and pseudo-suffixed items differently. There was significant priming of transposed letter morphological primes compared to a replaced letter prime condition (where one letter was switched out with a different letter, instead of transposed). However, priming was minimal for transposed letter pseudo-suffixed primes compared to replaced letter primes. The finding that transposed letter primes facilitated the target word with morphological, but not pseudo-suffixed prime words suggests that letter transpositions disrupt morpho-orthographic processing more than morpho-semantic processing. Diependaele and colleagues explain these results by suggesting that the morpho-orthographic system looks for morphemes directly from the stimuli, disregarding whole word information, and thus relies on fine-grained orthographic code, leading to morphological activation for morphological and pseudo-suffixed items. In contrast, the morpho-semantic system activates morphemes through whole-word form representations. Priming only occurs for morphological items and relies on coarse-grained code. The end result is that letter transpositions are detrimental for morpho-orthographic processing, which accounts for the removal of priming in pseudo-suffixed (but not morphological) primes. However, morphological priming is still possible through whole-word orthographic representations (morpho-semantic processing; Diependaele et al. 2013).

## Dyslexia and Morpho-Orthographic Segmentation

Quémart and Casalis (2015) conducted a study using French dyslexic readers, with a mean age of 13 years 6 months, reading matched controls with a mean age of 9 years 8 months, and chronological age matched controls with a mean age of 13 years 1 month. They used a morphological condition (cleaner-clean), a pseudo-derivation condition (corner-corn) an orthographic control (brothel-broth) and a semantic control (tulip-flower). They found significant morphological priming in all groups. There was no significant priming in the orthographic and semantic control conditions in all reading groups. This demonstrated that dyslexic children are able to process morphemes, even though they often have decoding difficulties. Results also demonstrated that children with dyslexia did not show significant priming effects when the prime-target pairs were the pseudo-derivation condition, whereas the reading control groups did show priming effects in this condition. This means that form overlap is not enough to process morphologically complex words into smaller parts in dyslexic readers. This suggests that dyslexic children rely more on a morpho-semantic level of representation rather than a morpho-orthographic level. If this is correct, then it is likely that dyslexic children use coarse-grained processing over fine-grained processing. This suggests that children with dyslexia rely more on morpho-semantic processing, compared to typically developing readers, who rely on morpho-orthographic processing (Quémart & Casalis, 2015).

**The Present Study**

The present study focuses on Diependaele and colleagues' (2013) results on letter transpositions and fine- and coarse–grained processing, as well as Quémart and Casalis's (2015) results demonstrating that developing poor readers rely more on morpho-semantic processing than on morpho-orthographic processing. The focus of the current study was to examine the differences between poor and strong developing readers in grade 6 and 2 in their morphological awareness skills. Quémart and Casalis (2015) demonstrated that dyslexic children rely more on morpho-semantic processing, whereas typically developing readers rely more on morpho-orthographic processing. If this is indeed the case, according to Diependaele and colleagues

(2013), then letter transpositions should not have as significant an impact on priming effects in morphological lexical decision tasks in poor readers, compared to adults and typically developing readers who will have less-significant priming due to their reliance on morpho-orthographic processing above morpho-semantic processing, particularly with opaque (pseudo-derived) words. In summary, the present study sought to determine whether children with poor reading skills, and beginning readers (grade 2), rely more on coarse-grained processing, rather than fine grained orthographic processing during morphological priming tasks, compared to typically developing readers, and more experienced readers. If they do, they may have an advantage over typically developing, and more experienced readers, on lexical decisions on target words with morphological properties that have letter transpositions.

## Hypotheses

If poor readers rely more on morpho-semantic processing (Quémart & Casalis, 2015), compared to typical, or strong readers, then they should benefit from coarse-grained processing. In comparison, as reading improves and readers have more exposure to print, they adapt a more fine-grained processing in morpho-orthographic segmentation. Fine-grained processing is assumed to rely more on morpho-orthographic processing, rather than morpho-semantic (Diependaele et al., 2013). If this is correct, then children who have difficulties reading will focus more on morpho-semantic processing, and therefore will subsequently rely more on a whole-word approach to the lexical decision task. Due to this, a transposed letter effect (which would create difficulties for fine-grained processing, as each letter position is crucial in fine grained processing) would not have as large an impact on poor compared to typical readers.

It is expected that the youngest age group tested (grade 2, reading age control) will have significant priming in the transposed letter condition with regular morphological primes, because they should rely most on coarse-grained processing (Diependaele et al., 2013). The good grade 6 readers will have a smaller priming effect in the letter transposition conditions, because it is expected that they will be starting to use fine-grained orthographic processing as the more-preferred strategy. They will still use morpho-semantic processing; however, there will be a general shift to morpho-orthographic processing as their preferred strategy, which would make it more difficult for them to be primed with words that have letter transpositions, due to the need for precise letter position in morpho-orthographic processing.

In terms of poor readers versus good readers, poor readers in grade two should ultimately do the worst on the task, relative to good readers in grade two, and poor and good readers in grade 6. However, poor readers in grade 6 may have markedly similar skills to good readers in grade 2. This may provide the study with a reading level matched control group, for the poor readers in grade 6.

Poor readers in grade 6 may have markedly similar skills to good readers in grade 2. This group (good readers in Grade 2) will provide the study with a reading level matched control group, for the poor readers in grade 6. If, however, there is a distinct and enduring processing difference between poor and good readers in general, then the reading age control will perform better (show less priming in the letter-transposed condition) than the poor readers in Grade 6 (showing that this group's pattern of performance is not a function of exposure to reading).

From the explanation above, the hypotheses are as follows. For grade 2 poor readers, there should be priming in the morphological prime condition, as well as in the morphological condition with a transposed letter prime. Since they are early in their reading development, they will be using coarse-grained processing, so the transposed letter effect will still work to prime, since they are not focused on precise letter order. From what has already been demonstrated, they should have no problem using a morphologically related prime, just as dyslexic readers have no trouble with this (Quémart & Casalis, 2015). There should be no priming in the pseudo-derivation condition for grade 2 children with either an intact, or transposed letter primes, because at this early stage of reading development, it has been demonstrated that they do not benefit from primes that are pseudo-derived (Quemart & Casalis, 2015).

In grade 2 good readers, for truly morphologically related primes, there should be priming in both the morphologically-related prime condition, and the transposed letter morphologically related prime condition. This is expected because these readers should still be preferring coarse-grained processing at this early stage in reading. In the pseudo-derivation conditions, it is unknown whether or not grade 2 readers will benefit from priming. If readers are already sensitive to morphological information in the pseudo-derivation condition, then they should benefit from priming in both the intact, and transposed letter pseudo-derived priming conditions. However, if these readers do not have sensitivity to morphological information yet, they will not benefit from either pseudo-derived condition.

For grade six poor readers, it is hypothesized that they will benefit from morphologically related primes, as well as morphologically related, transposed letter primes. Their reading skills will be similar to those of good grade 2 readers, in that they will still be relying on coarse-grained processing, so letter order will not interfere with priming. They will not benefit from priming in the pseudo-derived intact, or letter transposed conditions, as demonstrated by Quémart and Casalis (2015), with dyslexic readers.

For good readers in grade 6, it is expected that their reading will be more similar to typical adult readers. They will benefit from priming in the morphologically related, intact priming condition. They may benefit from the morphologically related, transposed letter prime condition, but it will be markedly weaker than the intact priming condition. In adult typical readers, the priming in this condition is much weaker than the priming in the intact condition. For grade 6 good readers, it is possible they will rely enough on fine-grained processing to have the same outcome as adults, or it may be the case that they still rely on coarse-grained processing, so their priming in the intact and transposed letter conditions may be somewhat similar. For pseudo-derived primes, it is expected that skilled grade 6 readers will have developed enough sensitivity to morphological knowledge to show priming in the pseudo-derived priming conditions. They should show priming in the intact condition, but for the transposed letter condition, the priming effect will depend on whether they rely on fine or coarse-grained processing. If they rely more on coarse-grained processing, the pseudo-derived transposed letter primes will be as effective as intact. If they rely more on fine-grained processing, they will have decreased priming effects compared to intact primes.

Diependaele and colleagues (2013) have demonstrated, that for typical adults, there was strong priming for the morphologically related, intact primes. There was priming for the morphologically related, transposed letter primes, but to a smaller extent. There were priming effects in the pseudo-derived, intact condition. However, there was no priming for the pseudo-derived transposed letter primes condition. The adults in the present study are expected to follow

Table 1.

*Hypotheses*

| Reader Group | Morphological Intact | Morphological Transposed | Pseudo-suffixed Intact | Pseudo-suffixed Transposed |
|---|---|---|---|---|
| Grade 2 poor readers | priming | priming | no priming | no priming |
| Grade 2 good readers | priming | priming | ? | ? |
| Grade 6 poor readers | priming | priming | no priming | no priming |
| Grade 6 good readers | priming | weaker priming | priming | weaker priming than intact or no priming |
| Adult readers | priming | priming | priming | no priming |

the same results.

## Method

**Participants**. 214 elementary school children (grades 2 and 6) participated in the study. Sixty-two undergraduate students from the University of Manitoba participated as well. Participants were in grade 2 and 6. Of these participants, participants were selected as good readers as poor readers, based on scores from the TOWRE-2. A score of 90 and above was considered a good reader, and 89 and below were considered poor readers. Elementary participants were recruited from schools from the Winnipeg School Division (See Appendix A for parental consent form and questionnaire).

**Materials and Apparatus.** The participants were assessed on the TOWRE-2, CTOPP-2, PPVT-4, and WASI-II.

**Reading Fluency.** The Test of Word Reading Efficiency, Second Edition (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012) assesses the ability to read words fluently, and the ability to read phonemically regular non-words (Torgesen et al., 2012). Participants completed both subtests, the Sight Word Efficiency subtest, which measures the number of real words listed that can be identified in 45 seconds, and the Phonemic Decoding Efficiency subtest, which assesses how many pronounceable nonwords an individual can accurately read in 45 seconds (Torgesen et al., 2012). Participants were asked to read aloud the words in each list. There are 108 word items and 66 pseudo-word items. The standard method of administration was used. These two subtests together contribute to a Total Reading Efficiency composite score. This standardized score was used later in the data analysis. The reliability coefficients for alternate forms and test retest for the same form exceed .90 (Torgesen et al. 2012).

**Receptive Vocabulary.** The Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4

Dunn & Dunn, 2007) was used to measure participants' receptive vocabulary knowledge (Sullivan et al., 2014). In a given item, participants are shown four pictures and are asked to point to the one that best represents the meaning of a word that has been verbally presented (Sullivan et al., 2014). There are 228 items. The standard method of administration was used. The PPVT-4 gathers a single standardized score of receptive vocabulary, which is what was used for interpretation purposes in this study. The PPVT-4 has reliability and validity coefficients in the .90's range (Dunn & Dunn, 2007).

**Phonological Awareness.** The Comprehensive Test of Phonological Processing-Second Edition (CTOPP-2, Wagner, Torgesen, Rashotte & Pearson, 2013) is a test of phonological processing. Three subtests were used for the purposes of this study. The Elision subtest measures the ability to remove phonological segments from spoken words to form other words. Participants were asked to say a word, such as "bold", and then to say the word without a specific sound, such as the "b", to say "old". This subtest contains 20 items. Raw scores were used to analyze the data. The Rapid Digit Naming subtest measures the ability to rapidly name numbers. Participants were shown a set of numbers, and asked to say each number out loud in order, as fast as possible. The time of completion is measured to score the test. This test is made up of 36 items. Finally, the Rapid Letter Naming measures the ability to rapidly name letters. It was conducted the same way as Rapid Digit Naming, and has the same number of items. The rapid naming subtests measure the ability to proficiently retrieve phonological information from long-term memory, and the ability to perform a series of operations rapidly, and repeatedly (Wagner et al., 2013). Raw scores were used to analyze the data. The standard method of administration was used for each subtest. The reliability of the subtests and composites have average internal consistency coefficients for the subtests that exceed .80. The average internal consistencies for the composites are all .85 or higher (Wagner et al., 2013). The CTOPP-2 scores were used as control measures, ruling out phonological awareness and rapid naming skills as the reasons for differences in this study.

**Nonverbal Intelligence**. The Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II, Wechsler, 2011) is a test that measures intelligence, including intellectual disabilities or giftedness. For this study the Matrix Reasoning subtest was used to measure visual and fluid intelligence, spatial ability and perceptual organization. Participants view 30 incomplete picture-matrices and are required to choose one of five options that correctly completes the matrix (Wechsler, 2011). A raw score is given on this, and is transformed into a T-score, and then transformed again into a scaled score, which was used for data analysis. The standard method of administration was used. Internal consistency reliability coefficients range from .87 to .91 for the subtest scores, and for the composite scores they range from .92 to .96 for the child sample (Wechsler, 2011). For the adult sample, the reliability coefficients for the subtest scores ranged from .90-.92, and the composites ranged from .94-.97 (Wechsler, 2011). The test-retest reliability for the child sample ranges from .79-.90. The adult sample ranges from .83-.94 for the subtests (Wechsler, 2011). The WASI-II was used to rule out intellectual disability as a reason for differences among students in this study.

**Lexical Decision Task.** The task used in this study was a masked priming lexical decision task. For the adult sample, the task was presented on a Dell Precision M4800 microcomputer, and developed using e-Prime v. 2.0. For the child sample, a Dell Precision 7510 microcomputer was used to present the task. Children entered lexical decisions using a computer mouse. They were asked to respond as fast as they could whether they thought the stimulus that appeared on the screen is a word or not. They were required to click the left button to respond “yes” that the letters are a word, and click the right button for “no” that stimulus is not a word.

There were three types of prime words used in the task (see appendix A for all words). One type was morphologically related condition, (*cleaner-CLEAN*). The second was a pseudo-derivation type, where the primes can be parsed into existing morphemes, but were semantically unrelated to the target (*corner-CORN*). The third was an orthographic control, where the primes were orthographically related to the target, because the prime word included the target, but they cannot be parsed into existing morphemes ( *scandal-SCAN* - because “dal” is not an English suffix ending). This is an important control condition, because it was expected that there would be no priming here, where there was priming expected in the other conditions. An additional set of unrelated words were included, with an equal number as the three combined prime type items. This was used as a control measure to assess the amount of priming against the related prime/target pairs. Unrelated prime words had no relation to the target words, and thus were expected not to show priming effects. Each target and prime word was matched on word frequency, orthographic neighbourhood size, phonological neighbourhood size, length in letters, and length in phonemes. The primes were also matched in orthographic prime-target overlap, and semantic prime-target relatedness. The unrelated word primes and the related word primes were also matched on letter length and frequency. The word lists were taken from a combination of two studies; Beyersmann and colleagues (2012) and Beyersmann and colleagues (2016), as well as additional words brought in by the author. For each of these word types, the words were split into two conditions; a correctly spelled (intact) condition and a transposed letter condition. The prime words in the transposed letter condition had two letters switched at the morpheme boundary (the last letter of the base word and the first letter of the suffix or pseudo-suffix were switched, e.g., *corenr*). There was also an equal number of non-word targets as word targets, to ensure the participants were not simply clicking yes for every condition. Altogether, there were 10 prime-target pairs in each condition; transposed morphological related, transposed morphological, unrelated, transposed pseudo-derived related, transposed pseudo-derived unrelated, transposed orthographic control related, transposed orthographic control unrelated, intact morphological related, intact morphological unrelated, intact pseudo-derived related, intact pseudo-derived unrelated, intact orthographic control related and intact orthographic control unrelated, totalling 120 items. There were 120 non-words dispersed among these items, for a total of 240 items per participant (see Appendix A for a complete list of items used in the task). The items were counterbalanced. Items were split into four different lists, with differing orders of the items. Each participant was randomly assigned to the list of items they received.

Each trial followed this sequence: a fixation cross was displayed in the middle of the screen for 1000 milliseconds (ms); then a forward mask consisting of a row of eight hash marks for 800 ms was displayed; then the prime stimulus appeared in lowercase letters presented for 60 ms; finally, the target stimulus was presented in uppercase letters. The target remained on the screen until the participant responded, or for a maximum of 3000 ms. Participants were instructed to respond as fast and accurately as possible, whether the target was a real word or not. Each subsequent trial followed immediately after the child gave a response. The presence of a prime was not mentioned. Each participant completed 10 practice trials before starting the task. The trials in each condition were randomly ordered. There was a break at the mid-point of the task.

It should be noted that instruction in morphology only begins in grade 3 in the Manitoba English Language Arts curriculum. It begins with students using semantic and graphophonic cues, such as high-frequency sight words, structural analysis to identify prefixes, suffixes, compound words, contractions, and singular and plural words to construct and confirm meaning

(Manitoba Education and Training, 1996). Students continue to build these skills until grade 6.

**Procedure.** The child participants in the study were tested at their schools. Each child was taken into a small room individually to perform the tasks. The measures were alternated, between computer tasks and pencil and paper tasks, to prevent fatigue. Each child participated in two blocks of testing, forty minutes each block. For adult participants, each was tested individually in the reading lab at the University of Manitoba.

## Results

Lexical decisions based on target words were analyzed as follows. Incorrect responses were removed from the reaction time (RT) analysis (18 % of all data). RT's were inverse transformed. All response times that fell below 200 ms and above 3000 ms were removed from the data set (4.9% of the data). Any participant that had more than 25% error rates were removed from the data (61 participants, 28.5% of participants). The make up of the students with error rates that exceeded inclusion criteria are as follows; 1 grade 6 poor reader (1.6%), 3 grade 6 good readers (4.9%), 32 grade 2 poor readers (52.5%), and 25 good grade 2 readers (41%). It should be noted that 28.5% of participants having error rates larder than 25% is unusually large for this type of study. Statistics in recent studies have demonstrated rates from 0 – 5% of participants (Beyersmann, Grainger, Casalis, & Ziegler, 2015; Beyersmann, Castles & Coltheart, 2012; Beyersmann, McCormick, & Rastle, 2013). However, many of these studies were conducted in french, and it may be the case that English readers do not follow the same morphological developmental trajectory. In addition, the sample in this study involved many students in grade 2, which is younger than the majority of previous studies using this task. In examining the error rates, 93.5% of the students excluded due to high error rates were grade 2 students. This supports the notion that the majority of children of this age may be too young to perform the task accurately. Four students chose not to participate in the task, or discontinued part way through, and were removed from the study. After data trimming, 154 child participants remained in the study (76 good grade 6 readers, 30 poor grade 6 readers, 48 good grade 2 readers). Grade 2 poor readers were removed from the study as there were not enough participants who met the performance criteria for inclusion. Due to this, the grade 2 poor reading group will not be discussed further in this study. Sample characteristics are shown below (table 1). Control measures were used to demonstrate group equivalence on phonological awareness, vocabulary, reading fluency and nonverbal intelligence. To rule out low intelligence, a criterion for inclusion was used for the nonverbal intelligence measure (Matrix Reasoning subtest of the WASI-II), of a t-score of 30. No participants were excluded based on this criterion. 62 adult participants were recruited for the study. One participant was omitted due to having an error rate above 25%, and four participants did not complete the descriptive measures, therefore were excluded from the

Table 2.

*Participant Characteristics*

| | Reader Group | | | |
|---|---|---|---|---|
| Variable | Grade 6 Good | Grade 6 Poor | Grade 2 Good | Adult Readers |
| Age (years)[a] | M = 11.59 | M = 11.43 | M = 7.14* (0.32) | M = 20.27 (3.70) |
| Vocabulary (PPVT-4)[b] | M = 104.11 (1.51) | M = 90.80* (2.41) | M = 106.54 (12.96) | M = 101.21 (9.60) |
| Reading Fluency (TOWRE-2)[b] | M = 112.93 (1.50) | M = 82.10* (2.39) | M = 113.25 (10.54) | M = 101.0 (10.38) |
| Word Reading Efficiency[c] | M = 80.24* (.91) | M = 61.93 (1.45) | M = 59.26 (7.97) | M = 87.52 (10.94) |
| Phonemic Decoding | M = 48.59* (1.01) | M = 25.27* (1.61) | M = 30.63* (10.54) | M = 51.31 (9.033) |
| Elision[d] | M = 29.13* (.65) | M = 22.03 (1.03) | M = 24.23 (6.71) | M = 29.55 (3.51) |
| Rapid Letter Naming[e] | M = 15.20* (.57) | M = 19.60* (.91) | M = 22.73* (5.08) | M = 12.57 (2.55) |
| Rapid Digit Naming[e] | M = 13.50* (.45) | M = 16.90* (.71) | M = 20.27* (4.98) | M = 12.11 (2.41) |
| Nonverbal Intelligence[f] | M = 50.09 (1.07) | M = 43.63* (1.71) | M = 51.27 (8.02) | M = 47.57 (8.98) |

Note: M = mean; * denotes a significant difference in that group relative to both of the other groups, coefficient in brackets = standard deviation; a. years; b. standard score (population mean 100, standard deviation 15); c. standard score; d. total correct; e. seconds; f. T-score (population mean 50, standard deviation 10).

analyses. All incorrect responses were removed from the data (.06%). Additionally, response times that fell below 200 ms and above 3000 ms were removed from the data set (.004%). This left 56 adult participants in the study.

Linear mixed-effect modelling was used to perform the analyses (Baayen, 2008; Baayen, Davidson, & Bates, 2008). Fixed and random effects were only included if they significantly improved the model's fit in a backward stepwise model selection procedure (Beyersmann, Cavalli, Casalis, & Cole, 2016). Models were selected using chi-square log-likelihood ratio tests with regular maximum likelihood parameter estimation (Beyersmann et al., 2016). Item number was included as a random factor to control for longitudinal task effects such as habituation or fatigue (Beyersmann et al., 2016). Prime words were classified in three ways (based on three independent variables). They were classified by suffix type (morphological; *teacher- TEACH*, pseudo-suffixed: *corner – CORN*, and orthographic: *scandal – SCAN*). The second classification was letter order (transposition type), intact (*corner-CORN*) or transposed (*corenr-CORN*). Finally, they were classified by whether they were related or unrelated to the target word (prime type). Reader group was classified as good or poor based on their TOWRE scores, with a composite score of 90 and above being considered a good reader. This was combined with age (grade 2 and grade 6) to make a reader group predictor variable (good grade 6 readers, poor grade 6 readers, and good grade 2 readers). Other fixed factors included in the model related to the subject were the measures of vocabulary, phonological awareness, nonverbal intelligence, and rapid naming. Additionally, frequency of words (age of acquisition, to control for frequency of target words) was included as a fixed factor related item. These fixed factors were included to ensure effects were solely caused by these variables. Each reading group will be discussed separately below.

**Grade 6 Good Readers**

To examine priming effects, separate models were created for grade 6 good readers, poor readers and grade 2 good readers. For good grade 6 readers two random factors were kept; subject and item. Nine fixed effects were kept including phonological awareness, nonverbal intelligence, prime type, suffix type, letter order, word frequency (AoA), rapid naming (phonological awareness), vocabulary, suffix type by prime type, suffix type by letter order, and prime type by letter order. The rest of this section reports the results of planned pairwise comparisons, based on the LSMEANS estimates of lmerTest. The full list of coefficients of the final model can be found in appendices C.I and C.II.

In terms of specific hypotheses, planned comparison analyses were conducted in order to examine further priming effects. Morphological related primes produced significantly faster responses than morphological unrelated primes ($p = 0.006$), suggesting priming was occurring. Consistent with hypotheses about good grade 6 readers, there were no significant differences between orthographic related, and unrelated primes ($p = 0.33$), suggesting that using a morphological, related prime does in fact speed up response times, compared to control conditions. It was hypothesized that there would be a priming effect using pseudo-suffixed intact primes however, pseudo-suffixed related primes did not result in faster response times than unrelated ($p = 0.28$) , suggesting priming was not occurring with pseudo-suffixed words. Consistent with hypotheses about good grade 6 readers, results indicate that related pseudo-suffixed words were not significantly different than orthographic control words ($p > 0.47$), suggesting that pseudo-suffixed prime words did not facilitate faster responses than a control group. It was hypothesized that morphological intact primes would produce significant priming.

Results demonstrated that morphological intact primes produced significantly faster response times than morphological transposed (p = < .01). It was hypothesized that there would be no priming, or minimal priming in the transposed pseudo-suffixed condition. The results demonstrated that pseudo-suffixed intact primes were only marginally significantly faster than pseudo-suffixed transposed (p = 0.085). Taken together these findings suggest that morpho-orthographic segmentation was not occurring for this reading group, and pseudo-suffixed prime words were not facilitating faster response times.

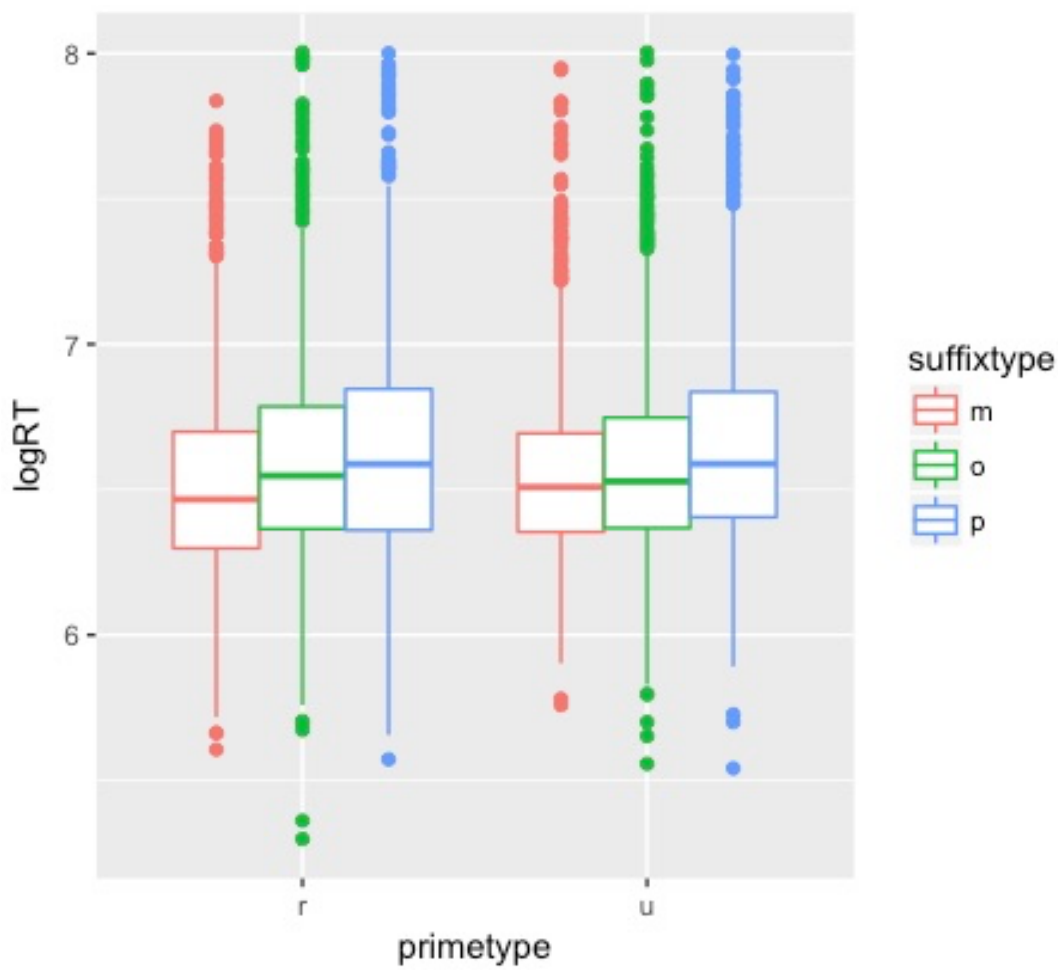

Figure 1: Suffix type by Prime type interaction for grade 6 good readers. This graph shows that morphological related primes resulted in significantly faster response times than morphological unrelated primes. This suggests that priming was occuring in the morphological condition. However, there was no significant differences between pseudo-suffixed and orthographic related primes compared to unrelated primes, suggesting priming was not occuring in these conditions.

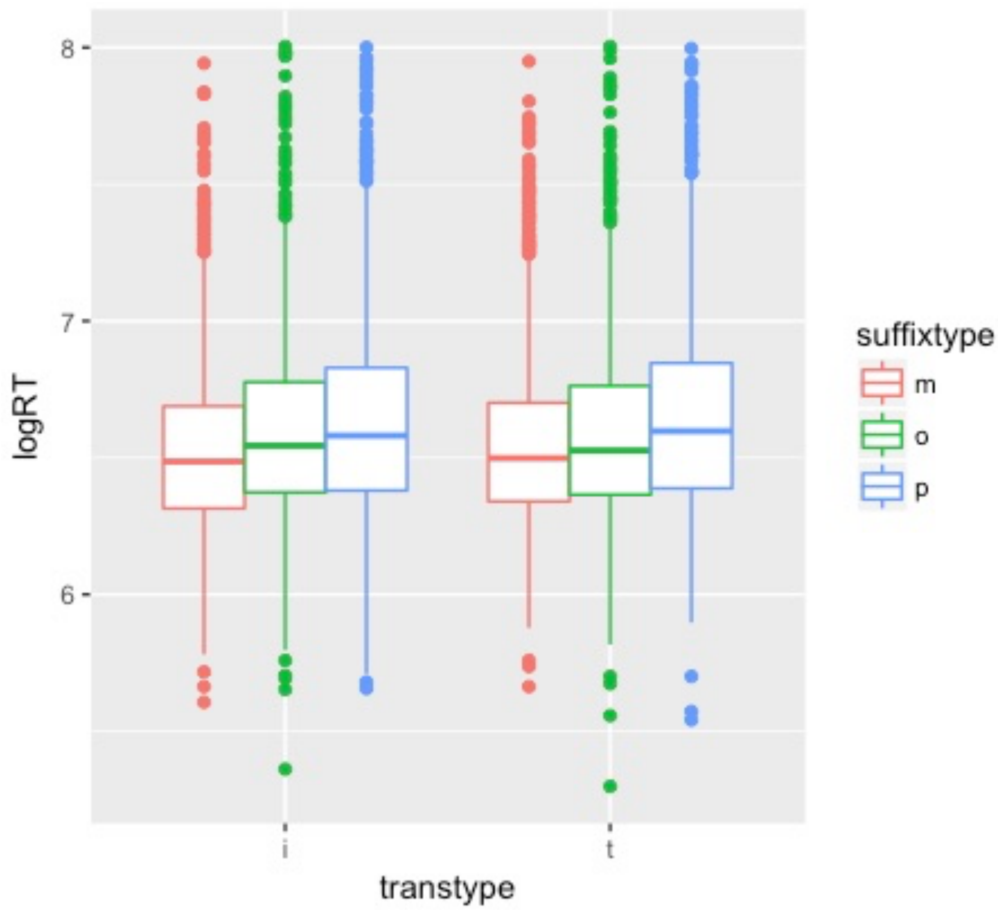


Figure 2: Suffix type by Letter order (transposition type) interaction for grade 6 good readers. This graph shows that morphological intact primes produced faster response times than morphological transposed primes. Additionally, pseudo-suffixed intact primes resulted in marginally faster response times than pseudo-suffixed transposed primes. This suggests that grade 6 good readers were using fine-grained processing, where letter transpositions interfered with response times.

## Grade 6 Poor Readers

A model was created for grade 6 poor readers that included subject and item as random factors, along with four fixed effects: word frequency, prime type, suffix type and letter order. The rest of this section reports the results of planned pairwise comparisons, based on the

LSMEANS estimates of lmerTest. The full list of coefficients of the final model can be found in appendices C.III and C.IV.

Overall, planned comparisons demonstrated that related primes showed faster response times than unrelated ($p < .05$), suggesting that with this reading group primes related to target words produce fast response times. It was also found that intact words resulted in faster response times over transposed ($p < .01$), suggesting fine-grained processing is being used, where precise letter order is used in visual word recognition. However, it should be noted that since this was finding was a general trend overall across all conditions (related, unrelated, morphological, pseudo-suffixed, orthographic), this finding holds less weight, than if it were more specific, such as morphological intact being faster than morphological transposed. Additionally, morphological primes results in faster response times than orthographic ($p < .05$) and pseudo-suffixed primes ($p < 0.05$). Intact primes producing faster times than transposed primes overall ($p < 0.01$). However, despite these effects, in terms of hypotheses, it was hypothesized that there would be priming in the morphological intact condition, however there was no significant priming demonstrated. It was hypothesized that there would be priming in the morphological transposed condition, and this was not supported. It was thought that there would be no priming in the pseudo-suffixed intact condition, and pseudo-suffixed transposed condition, and this was supported, with no priming occurring in these conditions.

**Grade 2 Good Readers**

In terms of effects, two random effects were kept: subject and item. Three fixed effects were kept including prime type, word frequency (AOA), and rapid naming. Letter order and suffix type were not kept in the model. The rest of this section reports the results of planned pairwise comparisons, based on the LSMEANS estimates of lmerTest. The full list of coefficients of the final model can be found in appendices C.V and C..VI.

To examine the results relating to hypotheses, planned comparisons demonstrate that related primes were faster than unrelated primes overall ($p < .01$). This suggests that when prime words were related to target words, response times were faster. However, no other effects were found. In terms of expected results, it was hypothesized that there would be priming in the morphological intact, and morphological transposed conditions. No significant results were found in these conditions, suggesting these hypotheses were not supported. There were no specific hypotheses made regarding the pseudo-suffixed conditions (intact and transposed), because it was unknown whether grade 2 students would be sensitive to morpho-orthographic segmentation yet. There was no priming in either of these conditions, suggesting that these students were not sensitive to morpho-orthographic segmentation. In contrast to grade 6 poor readers, grade 2 readers did not show letter order effects at all. This suggests that letter order was not a factor in priming, which would suggest coarse-grained processing was taking place. Additionally, suffix type was not included in the model, suggesting no priming was occurring due to suffix type. This was an unexpected result, suggesting that morphological skills are not developed enough at this age to benefit from morphological relations. However, overall, primes related to target words resulted in faster response times, suggesting that children of this age and reading level were able to benefit from priming effects.

**Adult Readers**

To compare children with adults on word recognition, a group of undergraduate students also participated in the task (without addressing reading group and age). Two random effects were kept in the model, subject and item. Six fixed effects were kept; prime type, suffix type, letter order, word frequency (AoA), suffix type by prime type, and prime type by letter order. The rest of this section reports the results of planned pairwise comparisons, based on the LSMEANS estimates of lmerTest. The full list of coefficients of the final model can be found in appendices C.VII and C.VIII.

Planned comparisons demonstrated that morphologically related words resulted in faster response times over morphological unrelated ($p < 0.001$). This suggests that priming was occurring in the morphological condition. Additionally, pseudo-suffixed related words produced faster response times than pseudo-suffixed unrelated primes, suggesting priming was occurring in the pseudo-suffixed condition ($p < .01$). This suggests that adults were using morpho-orthographic segmentation in visual word recognition. However, there were no differential effects of letter order on suffix type. This suggests that there was no significant response times differences among morphological intact and morphological transposed primes, as well as pseudo-suffixed intact and pseudo-suffixed transposed primes. This does not support the hypotheses that there would be priming in the morphological intact, morphological transposed, and pseudo-suffixed intact conditions. This finding does support the hypothesis of no priming effects in the pseudo-suffixed transposed condition. Additionally, it is worth noting that there was an overall trend of related intact primes resulting in faster response times than related transposed primes ($p < .001$), suggesting that despite there being no differences among suffixes when letter order is manipulated, there is an overall effect of transposed primes resulting in slower response times than intact primes. This provides evidence that adults are using fine-grained processing during visual word recognition.

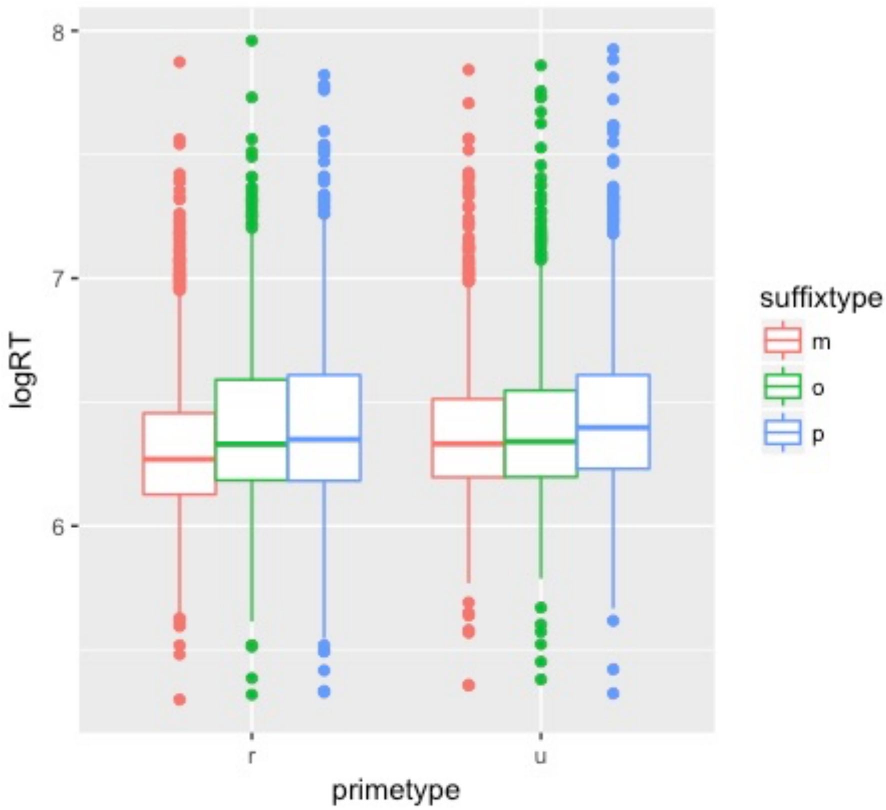


Figure 3: Prime type by Suffix type interaction for adult readers. This graph depicts the differences of suffix types (morphological, orthographic, and pseudo-suffixed) based on the manipulation of prime type (related to the target or unrelated to the target). The graph shows that morphological and pseudo-suffixed related prime-target pairs demonstrated significantly faster response times over unrelated prime-target pairs. This suggests that priming was occurring in the morphological and pseudo-suffixed conditions, but not in the orthographic condition.

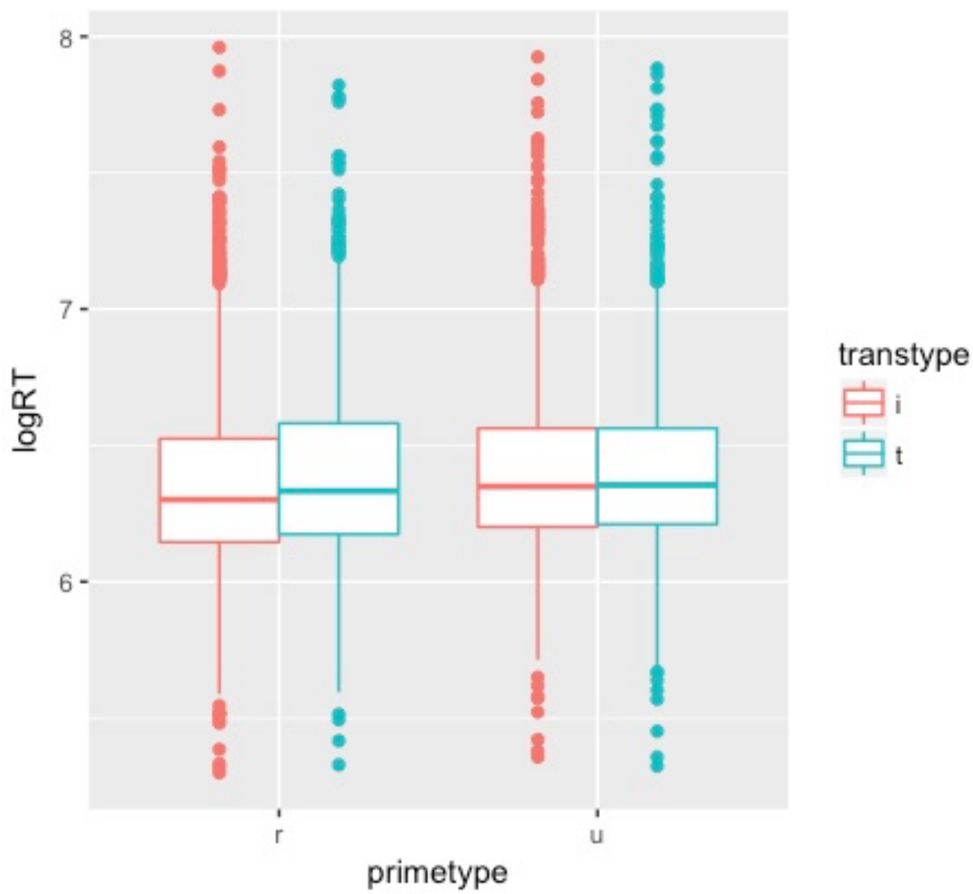


Figure 4: Prime type by Letter order interaction for adult readers. This graph shows the effects of prime type (related, unrelated) and letter order (intact, transposed). This demonstrates that overall, intact letter prime-target pairs resulted in faster response times than transposed letter prime-target pairs, but only when the prime and target words were related. This suggests that overall, letter transpositions interfered with response times when the primes were related to the target, suggesting adults were using fine-grained orthographic processing.

## Discussion

The discussion section is divided into four sections. The first section addresses the results from grade 6 good readers, the second addresses grade 6 poor readers, the third addresses grade 2 good readers, and finally adult readers. Following these sections, there is a section that addresses implications.

### Grade 6 Good Readers

The first hypothesis for grade 6 good readers was that there would be priming in the morphologically related intact condition. This results support this hypothesis. This suggests that children at this age and reading ability have substantial morphological awareness skills during word recognition, where they can use the morphologically related word, to quickly recognize a target word.

The second hypothesis was that there would be slower response times in the morphological transposed letter condition, than the intact condition. This hypothesis was supported as well. This suggests that transposed letters at the morpheme boundary interfered with making quick lexical decisions. This suggests that the children in this sample are already using fine-grained orthographic processing, where precise letter order matters in visual word recognition. This is an important finding, suggesting that by grade 6, good readers are using the same strategy as adult readers in terms of orthographic processing during visual word recognition.

The third hypothesis suggested that there would be priming in the pseudo-suffixed intact condition. Results indicated that pseudo-suffixed prime words did not produce significantly faster response times than orthographic control primes, therefore this hypothesis was not supported. This finding suggests that the participants were not using morpho-orthographic segmentation, because they did not treat the pseudo-suffix, for example, the *er* in *corner*, as related to the pseudo-suffix prime word (*corn*). This suggests that although they may be using fine-grained orthographic processing, they are not at a point where they have the morphological awareness to automatically parse words into bases and suffixes, regardless of whether the word is truly suffixed or not.

The final hypothesis for this participant group was that there would be less of a priming effect, or no priming effect at all using pseudo-suffixed transposed letter primes. This hypothesis was supported as there was only a marginal difference between pseudo-suffixed intact primes and pseudo-suffixed transposed letter primes. This result paired with the result that there was no priming effects in the pseudo-suffixed intact condition, would suggest that there was no priming in the transposed condition either. Due to the lack of morpho-orthographic segmentation (and the lack of priming in the pseudo-suffixed intact condition), it is difficult to decipher whether the results are consistent with Diependaele & colleagues theory that pseudo-suffixed words can only be primed when letters are intact, as there is only morpho-orthographic information being used, not morpho-semantic, in visual word recognition. What can be implied from this result is that children have enough morphological awareness that they can use it automatically during word recognition, however not enough awareness to use morpho-orthographic segmentation with pseudo-suffixed words.

**Grade 6 Poor Readers**

It was hypothesized that grade 6 poor readers would demonstrate priming effects for morphological intact prime target pairs. The results did not support this hypothesis. Overall, there was priming effect of morphological primes over orthographic and pseudo-suffixed, however there was no differentiation between intact morphological and transposed letter morphological, or related or unrelated morphological words. This suggests that there was no priming specifically for morphological intact words. This finding provides evidence that poor readers in grade 6 do not have the morphological awareness skills during word recognition to benefit from differential suffix priming in the lexical decision task.

In addition to priming in the morphological intact condition, it was hypothesized that there would be priming in the morphological transposed condition. Similar to the first hypothesis, this hypothesis was not supported. There were no differential effects within the morphological primes. As such, there was no additional priming in the morphological transposed condition. This finding is consistent with the first finding, that poor readers in grade 6 do not yet have the morphological awareness skills to use morphological information automatically, or unconsciously, during visual word recognition.

The third hypothesis stated that there would be no priming in the pseudo-suffixed intact condition. Since there were no differences separated between intact, transposed letter, or related and unrelated on pseudo-suffixed words as a whole, the hypothesis that no priming occurred is supported. However, this does not imply that the only reason is that these children are not using morpho-orthographic segmentation, due to the fact that there were no differences across morphological OR pseudo-suffixed words. This is consistent with prior results that demonstrate that children at this stage are not sensitive enough to morphological cues to use them during word recognition automatically.

The final hypothesis for grade 6 poor readers was that there would be no priming in the pseudo-suffixed transposed condition. Similar to the prior hypothesis, this was supported. This provides more evidence that students of this age and reading ability do not have the morphological skills to perform the task, and due to this, it is difficult to obtain whether the results are consistent with previous findings that transposed letter pseudo-suffixed primes can only be facilitated through morpho-orthographic information.

It should be noted that overall, there was a general trend of intact words having faster response times over transposed, suggesting that poor grade 6 readers are beginning to use fine-grained processing, where precise letter order matters in visual word recognition.

**Grade 2 Good Readers**

For grade 2 good readers it was hypothesized that there would be priming in the morphological intact condition. Similar to grade 6 poor readers, there were no differential effects of prime type (related/unrelated) or letter order (intact/transposed). This suggests that no priming occurred in this particular condition compared to the other morphological conditions (i.e., morphological transposed, morphological related, morphological unrelated). Consistent with grade 6 poor readers, grade 2 good readers did not show sensitivity to different suffixes in this task. In addition, suffix type was not even included in the model, suggesting there was no sensitivity whatsoever to different suffixes in any condition. In addition, letter order was not included in the model, suggesting letter order did not interfere at all with word recognition. This implies that these children were using coarse-grained orthographic processing during the task.

The second hypothesis for good grade 2 readers was that there would be priming in the transposed letter morphological condition. The results of this study did not support this hypothesis. Similar to findings above, there were no differences in prime type or letter order in the morphological condition, suggesting there was no significant priming in this particular condition.

There were no specific hypotheses made for the pseudo-suffixed conditions in grade 2 good readers on this task. This was because it was unknown whether grade 2 poor readers would be sensitive yet to morpho-orthographic segmentation. Due to the lack of sensitivity to different suffixes, it appears that there was no priming in either the intact, or transposed pseudo-suffixed conditions. It is assumed that children are not yet at the stage where morpho-orthographic segmentation is taking place, because they are not yet at a stage where differential priming is occurring dependent on suffix type.

**Adult Readers**

The goal of this study was to examine differences in processing in poor and good readers in grade 6 in early stages of visual word recognition. Adults were examined in order to provide a comparison against developing children. In terms of adult readers, the hypotheses were based on previous findings in a similar lexical decision task (Diependaele et al., 2013). In contrast to this study, there were no letter order differences  in response times between different types of suffixes. It was first hypothesized that there would be priming in the morphological intact condition and less priming effects (slower response times) in the morphological transposed condition. No differences between morphological intact and transposed primes suggest that these hypotheses were not supported. Similar to morphological primes, the lack of letter order effects suggests no differential priming in terms of pseudo-suffixed primes. The hypotheses stated there would be priming in the pseudo-suffixed intact letter condition, but only small, or no priming in the pseudo-suffixed transposed letter condition. Due to no significant differences between intact and transposed letter order in the results, these hypotheses are not supported.

The results for adults support the idea of morpho-orthographic segmentation occurring in adult readers, with response times being faster in pseudo-suffixed related primes compared to pseudo-suffixed unrelated primes. This is consistent with previous findings (Diependaele et al., 2013). The overall difference in response times between transposed and intact letter order suggest adults in this study were using fine-grained processing, where precise letter order matters in visual word recognition.  In contrast to previous literature, there were no significant differences between suffixes in regards to intact and transposed letter primes. In examining this unexpected finding, one theory why this occurred was the level of difficulty of the prime target pairs used in this study. The same words were used for all participants in the study (from grade 2 to adults). Due to this, the words may have been too easily recognized for adults to have to participate in any real orthographic processing. Instead, the words may have been recognized automatically enough that letter effects would not have mattered. The dual route model suggests that letter transpositions interfere with fine-grained orthographic processing, and subsequently disrupt sub-lexical morpho-orthographic segmentation. It is hypothesized that this is the only source of priming for pseudo-derived relations (*corner-corn*), and due to this, a transposed letter manipulation eliminates priming in this condition (Grainger & Ziegler, 2011). Conversely, true morphological relations (*farmer-farm)* benefit from morpho-semantic priming, through coarse-grained coding. For example, *faremr* strongly activates the whole-word orthographic representation for the word *farm* through shared morpho-semantic representations (Grainger and Ziegler, 2011). It is difficult from this study to confirm this theory, as letter order made no difference, whether primes were morphological or pseudo-suffixed words.

## Implications

There are several important implications to consider based on this study. In terms of differences between grade 6 poor readers and grade 2 good readers, the important finding is the differences on letter order. It appears that grade 6 poor readers are being affected by letter transpositions. This suggests that these students are using fine-grained processing. Consistent with Diependaele and colleagues (2013), it was found that morpho-orthographic segmentation and orthographic processing appear to be working independent of each other. Despite no morpho-orthographic priming occurring in the grade 6 students, they are beginning to use fine-grained processing. Generally, it has been thought that letter transpositions interfere with morpho-orthographic processing over morpho-semantic, but this study demonstrates that there is still interference from letter transpositions, even when students are still using a more morpho-semantic type of processing over morpho-orthographic processing. This suggest that letter precision is becoming important in identifying words, regardless if one is a good or poor reader, and regardless of whether they are using morpho-orthographic or morpho-semantic processing. It should be noted that for participant reading characteristics the grade 2 good readers were either not significantly different from grade 6 poor readers (i.e., word reading efficiency and elision) or they surpassed grade 6 poor readers (i.e., vocabulary, reading fluency, phonemic decoding, rapid letter naming, rapid digit naming, and nonverbal intelligence). This suggests that the major difference that may be mediating the result is age. In this case, this suggests that simply having more exposure to reading and print aids in the development of fine-grained orthographic processing.

In addition to differences between grade 6 poor readers and grade 2 readers, there were important differences between grade 6 good and poor readers. Good readers demonstrated priming in the morphological intact and transposed conditions. This did not occur for poor readers. When looking at the differences on reader group characteristics, the two groups differed significantly, with good readings having better scores on all reading skills (i.e., vocabulary, reading fluency, phonemic decoding, elision, nonverbal intelligence). This suggests that having strong reading skills in general, contribute to morphological knowledge, and ability to perform the lexical decision task. The lower scores achieved by the poor readers likely contribute to the inability to demonstrate morphological priming effects in the task.

Grainger & Ziegler (2011) demonstrated with adults that there is significant priming from intact morphological primes, transposed letter morphological primes, and intact pseudo-suffixed primes. The important finding they indicated was that no priming occurred from the transposed letter pseudo-suffixed condition. They suggested that letter transpositions interfere with fine-grained orthographic processing, and subsequently disrupt sub-lexical morpho-orthographic segmentation. They suggest that this is the only source of priming for pseudo-suffixed relations (*corner-corn*), and due to this, a transposed letter manipulation eliminates priming in this condition (Grainger & Ziegler, 2011). Conversely, true morphological relations (*farmer-farm*) benefit from morpho-semantic priming, through coarse-grained coding. For example, *faremr* strongly activates the whole-word orthographic representation for the word *farm* through shared morpho-semantic representations (Grainger and Ziegler, 2011). The present study found that adults did not show any differential letter order effects. Due to this, it is difficult to determine whether this study is consistent with Diependaele and colleagues' study confirming morpho-orthographic versus morpho-semantic processing.

In looking at differences between grade 6 good readers and adult readers, it appears that grade 6 readers showed more response time differences by manipulating letter order. For these readers, faster response times occurred for intact primes in the morphological and pseudo-suffixed conditions, compared to transposed letter primes. This suggests that children at this age are demonstrating fine-grained processing, similar to findings from previous adult studies, with letter transpositions differentially hindering morphological and pseudo-suffixed primes. Interestingly, this did not occur for adults, where there was an overarching trend of intact primes resulting in faster times than transposed, but no differences based on suffixes. This could be due to the level of difficulty of the words, with the words being too familiar and easily recognizable for adults. If this is the case, it may mean that adult participants are using morpho-semantic processing, and thus, coarse grained processing, due to the high frequency of the words used in the study, whereas grade 6 good readers are not yet at the point where these words are automatically recognized, and thus are using more of a fine-grained processing to recognize the words.

## Limitations and Future Directions

While the current study has notable strengths, some limitations arose that should be taken into consideration upon considering future research. In order to examine differences among suffix types and orthographic processing, a prime duration of 60 ms was used, which did not allow for sufficient priming in the pseudo-suffixed conditions. The current study suggests that children up to grade 6 are not at a point where they are automatic at parsing morphologically structured words into bases and suffixes the same way an adult would. However, recent studies are demonstrating that when prime duration is significantly longer than 60 ms (approximately 250), morpho-orthographic segmentation is beginning to occur. It would be useful to replicate this study using a longer prime duration, to discover whether the fine-grained processing they are using will hinder their ability to make lexical decisions on pseudo-suffixed transposed letter primes.

In addition to prime duration, poor readers in grade 6 and good readers in grade 2 displayed differences in their baseline reading characteristics, which made it difficult to compare the two groups overall. Future studies should seek to establish an increasingly optimal match between reader groups This will allow for a better understanding of developmental differences between groups.

In terms of adult readers, the contradictory results compared to other literature may suggest the words used were too easily recognizable for differential priming effects to occur. Due to the words being used by grade 2 students, the level of difficulty was substantially lower than it would have been had only adults participated in the study.

This study points to a significant area of need for students in elementary school with regard to reading ability. Children who are poor readers in terms of phonological skills, vocabulary, word decoding, and reading fluency, may have significant difficulties attending to morphological cues in word recognition. It may be worthwhile to have students be taught morphological skills explicitly in earlier grades (perhaps grades 1 or 2), in order to support the ability to recognize words in print while reading. Additional focus on students to have further teachings or practice in separating base words from suffixes, may be helpful. As of now, morpho-orthographic segmentation is not occurring at a rapid rate, suggesting that students in grades 2 and 6 are not as efficient as adults at word recognition.

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Appendix A: Parental Consent Form and Questionnaire

UNIVERSITY OF MANITOBA

Department of Psychology

**Visual Attention and Reading Study**
**Parent/Guardian Consent Form**
Richard Kruk, Department of Psychology
University of Manitoba

Name of Child (please print): ______________________________________
Child's date of birth: Month _____ Day _____ Year _____

CHECK HERE
____ I give permission for my child to participate in the study conducted by Richard Kruk.
____ I do NOT give permission for my child to participate in the study conducted by Richard Kruk.
Signature of Parent/Guardian: _______________________ Date: _________________
Researcher's Signature: ____________________________ Date: _________________
If you are interested in receiving a copy of a report of the final results, please write your mailing (or email) address below:

_______________________________________________________________________

If you are giving permission, please provide us with additional information (see next page)

University of Manitoba | Department of Psychology

**Visual Attention and Reading Study**
**Parent Questionnaire**

Please complete this questionnaire, as we would like to learn about your child and his/her reading and other experiences.

Name of child (please print): ____________________________________________

Child's gender (circle): Male Female

Please circle the approximate number of days per week your child spends reading at home:
Weekdays: 0 1 2 3 4 5
Weekends: 0 1 2

*On these days*, please circle the approximate number of minutes per day spent reading:
Weekdays: None About 30 About 60 About 90 More than 90; please estimate ____
Weekends: None About 30 About 60 About 90 More than 90; please estimate ____

Please circle the approximate number of days per week your child spends playing *interactive* video games (games with rapidly moving objects/scenes):
Weekdays: 0 1 2 3 4 5
Weekends: 0 1 2

*On these days*, please circle the approximate number of minutes per day spent playing *interactive* video games (games with rapidly moving objects/scenes):

Weekdays: None About 30 About 60 About 90 More than 90; please estimate ____
Weekends: None About 30 About 60 About 90 More than 90; please estimate ____

| Please indicate your highest level of education: | other parent/guardian (if applicable): |
|---|---|
| ___ Some High School | ___ Some High School |
| ___ High School | ___ High School |
| ___ post-secondary diploma/degree | ___ post-secondary diploma/degree |

Annual household income:
___ Less than $50,000
___ More than $50,000

Is your child fluent in English: Yes:____ No:_____
OR:

Main language spoken at home: ________________________________

Does your child require corrective lenses (eye glasses) for reading? Yes___ No ___

Does your child have special needs that could have an impact on his/her school experience?
Yes: ____ No: ____
**If yes**, please specify the nature of the special need(s):
____ ADHD (attention deficit hyperactivity disorder that was diagnosed)
____ Learning disability (e.g., reading disability, writing disability)
____ Other. Please specify the nature of the special need(s): _____________________

We are planning to conduct a **follow-up study** involving a small number of children at the University. If you are willing to have your child considered for this follow-up study, please indicate: (If you indicate 'YES' we will contact you at a later date)
_____ YES, I am willing to have my child considered for a follow-up study
_____ NO, I am NOT willing to have my child considered for a follow-up study
Please provide the best way to contact you to organize your child's involvement in the follow-up study.
Telephone: _____________________ Email: ____________________________

## Appendix B: Complete Lexical Decision Item List

| Unrelated Primes | Related Primes | Intact-Letter Primes | Transposed-Letter Primes | Target | Condition |
|---|---|---|---|---|---|
| smelly | walked | smelyl | walekd | WALK | Morphological |
| lovely | filled | lovley | fileld | FILL | Morphological |
| frosty | golden | frosyt | goledn | GOLD | Morphological |
| posted | crying | posetd | criyng | CRY | Morphological |
| liked | badly | likde | baldy | BAD | Morphological |
| weaker | drying | weaekr | driyng | DRY | Morphological |
| boards | opened | boarsd | opeend | OPEN | Morphological |
| mower | shyly | moewr | shlyy | SHY | Morphological |
| softer | flying | sofetr | fliyng | FLY | Morphological |
| tighter | playing | tighetr | plaiyng | PLAY | Morphological |
| doing | mixer | diong | miexr | MIX | Morphological |
| louder | buying | louedr | buiyng | BUY | Morphological |
| boiler | fixing | boielr | boielr | FIX | Morphological |
| robbery | teacher | robbeyr | teacehr | TEACH | Morphological |
| nearer | acting | neaerr | acitng | ACT | Morphological |
| waved | moody | wavde | mooyd | MOOD | Morphological |
| fuller | mainly | fulelr | mailny | MAIN | Morphological |
| stormy | farmer | storym | faremr | FARM | Morphological |
| named | lucky | namde | lucyk | LUCK | Morphological |
| messy | boxer | mesys | boexr | BOX | Morphological |
| filthy | harder | filtyh | haredr | HARD | Morphological |
| soften | trying | sofetn | triyng | TRY | Morphological |
| locker | eating | locekr | eaitng | EAT | Morphological |
| milky | layer | milyk | laeyr | LAY | Morphological |
| darker | creamy | darekr | creaym | CREAM | Morphological |
| leader | slowly | leaedr | slolwy | SLOW | Morphological |
| banker | deeply | banekr | deelpy | DEEP | Morphological |
| rainy | aimed | raiyn | aiemd | AIM | Morphological |
| loved | sadly | lovde | saldy | SAD | Morphological |
| stars | dirty | stasr | diryt | DIRT | Morphological |
| grassy | weaken | grasys | weaekn | WEAK | Morphological |
| bumpy | owner | bumyp | boexr | OWN | Morphological |
| postal | banker | posatl | owenr | BANK | Morphological |
| greedy | singer | greeyd | faremr | SING | Morphological |
| sleepy | killer | sleeyp | banekr | KILL | Morphological |
| nearly | hunter | nealry | sinegr | HUNT | Morphological |
| widely | reader | widley | deaelr | READ | Morphological |
| fruity | teller | fruiyt | hunetr | TELL | Morphological |
| lately | winner | latley | winenr | WIN | Morphological |
| oddity | tester | odidty | tesetr | TEST | Morphological |
| fluffy | pollen | flufyf | poleln | POLL | Pseudo-suffixed |
| petal | siren | peatl | siern | SIR | Pseudo-suffixed |
| acidic | bother | adiidc | botehr | BOTH | Pseudo-suffixed |
| zealous | brother | zeaolus | brotehr | BROTH | Pseudo-suffixed |
| bushy | cater | busyh | caetr | CAT | Pseudo-suffixed |
| faulty | corner | faulyt | corenr | CORN | Pseudo-suffixed |

| | | | | | |
|---|---|---|---|---|---|
| gawky | cower | gawyk | coewr | COW | Pseudo-suffixed |
| earthy | flower | eartyh | floewr | FLOW | Pseudo-suffixed |
| sticky | mister | sticyk | misetr | MIST | Pseudo-suffixed |
| pricey | mother | pricye | motehr | MOTH | Pseudo-suffixed |
| syrupy | ponder | syruyp | ponedr | POND | Pseudo-suffixed |
| bossy | proper | bosys | proepr | PROP | Pseudo-suffixed |
| smelly | shower | smelyl | shoewr | SHOW | Pseudo-suffixed |
| messy | taper | mesys | taepr | TAP | Pseudo-suffixed |
| milky | tower | milyk | toewr | TOW | Pseudo-suffixed |
| stormy | wander | storym | wanedr | WAND | Pseudo-suffixed |
| eater | slimy | eaetr | sliym | SLIM | Pseudo-suffixed |
| likely | easter | likley | easetr | EAST | Pseudo-suffixed |
| eggs | lady | egsg | layd | LAD | Pseudo-suffixed |
| fighting | shoulder | fighitng | shouledr | SHOULD | Pseudo-suffixed |
| older | scary | oledr | scayr | SCAR | Pseudo-suffixed |
| prayer | forest | praeyr | foerst | FOR | Pseudo-suffixed |
| bricks | poster | bricsk | posetr | POST | Pseudo-suffixed |
| tower | party | toewr | paryt | PART | Pseudo-suffixed |
| sleepy | listen | sleeyp | lisetn | LIST | Pseudo-suffixed |
| used | many | usde | mayn | MAN | Pseudo-suffixed |
| sandy | metal | sanyd | meatl | MET | Pseudo-suffixed |
| cats | army | cast | arym | ARM | Pseudo-suffixed |
| eaten | belly | eaetn | belyl | BELL | Pseudo-suffixed |
| nearly | fasten | nealry | fasetn | FAST | Pseudo-suffixed |
| beans | fairy | beasn | faiyr | FAIR | Pseudo-suffixed |
| others | united | othesr | unietd | UNIT | Pseudo-suffixed |
| clearly | million | clealry | mililon | MILL | Pseudo-suffixed |
| lower | every | loewr | eveyr | EVER | Pseudo-suffixed |
| editor | planet | ediotr | plaent | PLAN | Pseudo-suffixed |
| cheaper | factory | cheaepr | facotry | FACT | Pseudo-suffixed |
| wooden | sandal | wooedn | sanadl | SAND | Pseudo-suffixed |
| filling | country | fililng | counrty | COUNT | Pseudo-suffixed |
| warmer | hungry | waremr | hunrgy | HUNG | Pseudo-suffixed |
| caller | finish | calelr | fiinsh | FIN | Pseudo-suffixed |
| prayer | button | praeyr | butotn | BUTT | Orthographic-control |
| speaker | address | speaekr | adrdess | ADD | Orthographic-control |
| tender | freeze | tenedr | frezee | FREE | Orthographic-control |
| curled | single | cureld | sinlge | SING | Orthographic-control |
| tidying | against | tidiyng | agaisnt | AGAIN | Orthographic-control |
| early | think | earyl | thikn | THIN | Orthographic-control |
| salty | tease | salyt | teaes | TEA | Orthographic-control |
| fruity | window | fruiyt | winodw | WIND | Orthographic-control |
| ants | howl | anst | holw | HOW | Orthographic-control |
| sooner | carrot | sooenr | carrot | CAR | Orthographic-control |
| maps | beer | masp | bere | BEE | Orthographic-control |
| lighter | twinkle | lighetr | twiknle | TWIN | Orthographic-control |
| curly | sight | curyl | sigth | SIGH | Orthographic-control |
| risky | hotel | risyk | hoetl | HOT | Orthographic-control |
| oldest | farmer | oledst | faremr | FAR | Orthographic-control |

| | | | | | |
|---|---|---|---|---|---|
| player | carton | plaeyr | carotn | CART | Orthographic-control |
| cars | area | casr | arae | ARE | Orthographic-control |
| jelly | china | jelyl | chian | CHIN | Orthographic-control |
| bumpy | tooth | bumyp | totoh | TOO | Orthographic-control |
| snowy | begin | snoyw | beign | BEG | Orthographic-control |
| dusty | skirt | dusyt | skrit | SKI | Orthographic-control |
| magical | spinach | magiacl | spianch | SPIN | Orthographic-control |
| bags | menu | basg | meun | MEN | Orthographic-control |
| going | crown | giong | cronw | CROW | Orthographic-control |
| slower | turnip | sloewr | turinp | TURN | Orthographic-control |
| hunter | yellow | hunetr | yelolw | YELL | Orthographic-control |
| camped | starve | camepd | stavre | STAR | Orthographic-control |
| pipes | DISCO | pipse | disoc | DISC | Orthographic-control |
| gloomy | wonder | glooym | wodner | WON | Orthographic-control |
| rocky | pasta | rocyk | pasat | PAST | Orthographic-control |
| poetry | dragon | poerty | draogn | DRAG | Orthographic-control |
| lesser | pillow | lesesr | pilolw | PILL | Orthographic-control |
| bossy | camel | bosys | camle | CAME | Orthographic-control |
| richer | lesson | ricehr | lesosn | LESS | Orthographic-control |
| seeing | cashew | seieng | casehw | CASH | Orthographic-control |
| within | market | witihn | marekt | MARK | Orthographic-control |
| ninety | scrape | nintey | scraep | SCRAP | Orthographic-control |
| arming | fleece | arimng | flecee | FLEE | Orthographic-control |
| misty | stunt | misyt | stutn | STUN | Orthographic-control |
| asking | galaxy | asikng | galxay | GALA | Orthographic-control |

Appendix C.I: Grade 6 Good Reader R Output

| Fixed Effects | Estimate | Std. Error | DF | T -Value | P-Value |
|---|---|---|---|---|---|
| (Intercept) | 6.960e+00 | 1.718e-01 | 8.600e+01 | 40.516 | < 2e-16 |
| Suffix Type – Morphological | -6.240e-02 | 2.166e-02 | 1.910e+02 | -2.881 | 0.00441 |
| Suffix Type-Orthographic | -5.216e-02 | 2.198e-02 | 2.000e+02 | -2.373 | 0.01859 |
| Prime Type-Related | 5.954e-04 | 1.348e-02 | 7.679e+03 | 0.044 | 0.96477 |
| Letter Order - Intact | -6.937e-03 | 1.344e-02 | 7.667e+03 | -0.516 | 0.60578 |
| Word Frequency | 1.367e-01 | 2.594e-02 | 9.600e+01 | 5.271 | 8.34e-07 |
| Rapid Naming | -2.193e-03 | 9.795e-04 | 7.300e+01 | -2.239 | 0.02823 |
| Vocabulary | -3.140e-03 | 1.440e-03 | 7.300e+01 | -2.181 | 0.03243 |
| Prime Type-Related: Suffix Type – Morphological | -1.692e-02 | 1.596e-02 | 7.677e+03 | -1.060 | 0.28899 |
| Prime Type- Related: Suffix Type – Orthographic | 2.420e-02 | 1.655e-02 | 7.674e+03 | 1.462 | 0.14383 |
| Suffix Type – Morphological by Letter-Order Intact | -1.351e-02 | 1.594e-02 | 7.669e+03 | -0.847 | 0.39697 |
| Suffix Type – Orthographic by Letter Order Intact | 2.650e-02 | 1.654e-02 | 7.666e+03 | 1.602 | 0.10924 |
| Prime Type – Related by Letter Order Intact | -2.665e-02 | 1.312e-02 | 7.666e+03 | -2.031 | 0.04231 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom

Appendix C.II: Grade 6 Good Readers R Output Differences of LSMEANS

| Differences of LSMEANS | T -Value | Lower CI | Upper CI | P-Value |
|---|---|---|---|---|
| suffixtype m - o | -2.92 | -0.0853 | -0.0163 | 0.004 |
| suffixtype m - p | -4.20 | -0.1142 | -0.0410 | 1e-04 |
| suffixtype o - p | -1.45 | -0.0636 | 0.0100 | 0.151 |
| primetype r - u | -1.56 | -0.0232 | 0.0026 | 0.118 |
| transtype i - t | -2.42 | -0.0288 | -0.0030 | 0.016 |
| suffixtype:primetype mr - or | -3.73 | -0.1091 | -0.0336 | 3e-04 |
| suffixtype:primetype mr - pr | -4.28 | -0.1259 | -0.0463 | <2e-16 |
| suffixtype:primetype m r - m u | -2.75 | -0.0508 | -0.0085 | 0.006 |
| suffixtype:primetype m r - o u | -3.12 | -0.0977 | -0.0221 | 0.002 |
| suffixtype:primetype m r - p u | -4.91 | -0.1385 | -0.0591 | <2e-16 |
| suffixtype:primetype o r - p r | -0.72 | -0.0548 | 0.0254 | 0.470 |
| suffixtype:primetype o r - m u | 2.18 | 0.0040 | 0.0794 | 0.030 |
| suffixtype:primetype o r - o u | 0.98 | -0.0114 | 0.0343 | 0.325 |
| suffixtype:primetype o r - p u | -1.35 | -0.0675 | 0.0127 | 0.178 |
| suffixtype:primetype p r - m u | 2.80 | 0.0166 | 0.0962 | 0.006 |
| suffixtype:primetype p r - o u | 1.29 | -0.0140 | 0.0663 | 0.200 |
| suffixtype:primetype p r - p u | -1.08 | -0.0358 | 0.0103 | 0.279 |
| suffixtype:primetype m u - o u | -1.58 | -0.0680 | 0.0075 | 0.116 |
| suffixtype:primetype m u - p u | -3.44 | -0.1089 | -0.0294 | 8e-04 |
| suffixtype:primetype o u - p u | -1.92 | -0.0790 | 0.0012 | 0.057 |
| suffixtype:transtype m i - o i | -3.71 | -0.1085 | -0.0331 | 3e-04 |
| suffixtype:transtype m i - p i | -4.20 | -0.1241 | -0.0446 | <2e-16 |

| | | | | |
|---|---|---|---|---|
| suffixtype:transtype m i - m t | -3.13 | -0.0549 | -0.0126 | 0.002 |
| suffixtype:transtype m i - o t | -3.37 | -0.1024 | -0.0268 | 9e-04 |
| suffixtype:transtype m i - p t | -5.21 | -0.1444 | -0.0649 | <2e-16 |
| suffixtype:transtype o i - p i | -0.67 | -0.0536 | 0.0265 | 0.505 |
| suffixtype:transtype o i - m t | 1.94 | -0.0007 | 0.0748 | 0.054 |
| suffixtype:transtype o i - o t | 0.54 | -0.0166 | 0.0291 | 0.593 |
| suffixtype:transtype o i - p t | -1.67 | -0.0739 | 0.0063 | 0.098 |
| suffixtype:transtype p i - m t | 2.51 | 0.0108 | 0.0904 | 0.013 |
| suffixtype:transtype p i - o t | 0.97 | -0.0204 | 0.0600 | 0.332 |
| suffixtype:transtype p i - p t | -1.73 | -0.0433 | 0.0028 | 0.085 |
| suffixtype:transtype m t - o t | -1.60 | -0.0687 | 0.0071 | 0.110 |
| suffixtype:transtype m t - p t | -3.52 | -0.1107 | -0.0311 | 6e-04 |
| suffixtype:transtype o t - p t | -1.97 | -0.0802 | 0.0001 | 0.051 |
| primetype:transtype r i - u i | -2.55 | -0.0418 | -0.0054 | 0.011 |
| primetype:transtype r i - r t | -3.15 | -0.0475 | -0.0110 | 0.002 |
| primetype:transtype r i - u t | -2.81 | -0.0445 | -0.0079 | 0.005 |
| primetype:transtype u i - r t | -0.61 | -0.0238 | 0.0126 | 0.545 |
| primetype:transtype u i - u t | -0.28 | -0.0208 | 0.0156 | 0.779 |
| primetype:transtype r t - u t | 0.32 | -0.0152 | 0.0213 | 0.746 |

Note: CI = Confidence Interval

Appendix C.III: Grade 6 Poor Readers R Output

| Fixed Effects | Estimate | Std. Error | DF | T -Value | P-Value |
|---|---|---|---|---|---|
| (Intercept) | 6.51099 | 0.06177 | 119.80000 | 105.414 | < 2e-16 |
| Suffix Type – Morphological | -0.05286 | 0.02098 | 93.70000 | -2.520 | 0.01343 |
| Suffix Type-Orthographic | -0.01560 | 0.02126 | 95.50000 | -0.734 | 0.46480 |
| Prime Type-Related | -0.02698 | 0.01148 | 2960.50000 | -2.350 | 0.01886 |
| Letter Order - Intact | -0.03190 | 0.01132 | 2882.10000 | -2.818 | 0.00486 |
| Word Frequency | 0.15842 | 0.02947 | 91.20000 | 5.376 | 5.82e-07 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom

Appendix C.IV: Grade 6 Poor Readers R Output Differences of LSMEANS

| Differences of LSMEANS | Estimate | Std. Error | DF | T -Value | Lower CI | Upper CI | P-Value |
|---|---|---|---|---|---|---|---|
| suffixtype m - o | 0.0 | 0.0203 | 97.8 | -1.84 | -0.0775 | 0.0030 | 0.069 |
| suffixtype m - p | -0.1 | 0.0210 | 93.7 | -2.52 | -0.0945 | -0.0112 | 0.013 |
| suffixtype o - p | 0.0 | 0.0213 | 95.5 | -0.73 | -0.0578 | 0.0266 | 0.465 |
| primetype r - u | 0.0 | 0.0115 | 2960.5 | -2.35 | -0.0495 | -0.0045 | 0.019 |
| transtype i - t | 0/0 | 0.0113 | 2882.1 | -2.82 | -0.0541 | -0.0097 | 0.005 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom; CI = Confidence Interval

Appendix C.V: Grade 2 Good Readers R Output Fixed Effects

| Fixed Effects | Estimate | Std. Error | DF | T -Value | P-Value |
|---|---|---|---|---|---|
| (Intercept) | 7.262e+00 | 2.913e-01 | 4.900e+01 | 24.930 | < 2e-16 |
| Prime Type-Related | -2.713e-02 | 9.684e-03 | 4.457e+03 | -2.802 | 0.0051 |
| Word Frequency | 1.962e-01 | 2.857e-02 | 9.600e+01 | 6.868 | 6.34e-10 |
| Rapid Naming | -6.025e-03 | 2.766e-03 | 4.600e+01 | -2.179 | 0.0345 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom

Appendix C.VI: Grade 2 Good Readers R Output Differences of LSMEANS

| Differences of LSMEANS | Estimate | Std. Error | DF | T -Value | Lower CI | Upper CI | P-Value |
|---|---|---|---|---|---|---|---|
| primetype r - u | 0 | 0.0097 | 4458 | -2.8 | -0.0461 | -0.0081 | 0.005 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom; CI = Confidence Interval

Appendix C.VII: Adult Readers R Output Fixed Effects

| Fixed Effects | Estimate | Std. Error | DF | T -Value | P-Value |
|---|---|---|---|---|---|
| (Intercept) | 6.301e+00 | 5.282e-02 | 1.570e+02 | 119.307 | < 2e-16 |
| Suffix Type – Morphological | -4.562e-02 | 1.763e-02 | 1.440e+02 | -2.587 | 0.010657 |
| Suffix Type-Orthographic | -3.341e-02 | 1.776e-02 | 1.480e+02 | -1.881 | 0.061907 |
| Prime Type-Related | -1.624e-02 | 1.161e-02 | 5.797e+03 | -1.399 | 0.161973 |
| Letter Order - Intact | 1.456e-05 | 8.016e-03 | 5.786e+03 | 0.002 | 0.998551 |
| Word Frequency | 8.318e-02 | 2.282e-02 | 9.900e+01 | 3.646 | 0.000428 |
| Prime Type-Related: Suffix Type – Morphological | -3.202e-02 | 1.380e-02 | 5.802e+03 | -2.321 | 0.020348 |
| Prime Type- Related: Suffix Type – Orthographic | 2.675e-02 | 1.428e-02 | 5.800e+03 | 1.873 | 0.061117 |
| Prime Type – Related by Letter Order Intact | -2.750e-02 | 1.135e-02 | 5.785e+03 | -2.424 | 0.015388 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom

Appendix C.VIII: Adult Readers R Output Differences of LSMEANS

| Differences of LSMEANS | Estimate | Std. Error | DF | T -Value | Lower CI | Upper CI | P-Value |
|---|---|---|---|---|---|---|---|
| suffixtype m - o | 0.0 | 0.0153 | 128.7 | -2.72 | -0.0719 | -0.0113 | 0.007 |
| suffixtype m - p | -0.1 | 0.0162 | 104.1 | -3.80 | -0.0938 | -0.0294 | 2e-04 |
| suffixtype o - p | 0.0 | 0.0163 | 104.5 | -1.23 | -0.0523 | 0.0122 | 0.221 |
| primetype r - u | 0.0 | 0.0057 | 5800.8 | -5.57 | -0.0429 | -0.0206 | <2e-16 |
| transtype i - t | 0.0 | 0.0057 | 5785.8 | -2.42 | -0.0249 | -0.0026 | 0.015 |
| suffixtype:primetype m r - o r | -0.1 | 0.0168 | 186.4 | -4.23 | -0.1041 | -0.0378 | <2e-16 |
| suffixtype:primetype m r - p r | -0.1 | 0.0176 | 145.4 | -4.40 | -0.1125 | -0.0428 | <2e-16 |
| suffixtype:primetype m r - m u | -0.1 | 0.0094 | 5803.0 | -6.59 | -0.0804 | -0.0436 | <2e-16 |
| suffixtype:primetype m r - o u | -0.1 | 0.0168 | 186.2 | -4.43 | -0.1073 | -0.0411 | <2e-16 |
| suffixtype:primetype m r - p u | -0.1 | 0.0176 | 144.9 | -6.11 | -0.1425 | -0.0728 | <2e-16 |
| suffixtype:primetype o r - p r | 0.0 | 0.0178 | 148.6 | -0.37 | -0.0418 | 0.0285 | 0.708 |
| suffixtype:primetype o r - m u | 0.0 | 0.0168 | 185.3 | 0.53 | -0.0242 | 0.0422 | 0.595 |
| suffixtype:primetype o r - o u | 0.0 | 0.0101 | 5799.1 | -0.32 | -0.0230 | 0.0166 | 0.748 |
| suffixtype:primetype o r - p u | 0.0 | 0.0178 | 148.3 | -2.06 | -0.0718 | -0.0015 | 0.041 |
| suffixtype:primetype p r - m u | 0.0 | 0.0176 | 144.9 | 0.89 | -0.0192 | 0.0505 | 0.377 |
| suffixtype:primetype p r - o u | 0.0 | 0.0178 | 148.5 | 0.19 | -0.0317 | 0.0385 | 0.847 |
| suffixtype:primetype p r - p u | 0.0 | 0.0101 | 5800.7 | -2.97 | -0.0498 | -0.0102 | 0.003 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| suffixtype:primetype m u - o u | 0.0 | 0.0168 | 185.2 | -0.73 | -0.0453 | 0.0209 | 0.468 |
| suffixtype:primetype m u - p u | 0.0 | 0.0176 | 144.4 | -2.59 | -0.0805 | -0.0108 | 0.011 |
| suffixtype:primetype o u - p u | 0.0 | 0.0178 | 148.2 | -1.88 | -0.0685 | 0.0017 | 0.062 |
| primetype:transtype r i - u i | 0.0 | 0.0080 | 5793.1 | -5.68 | -0.0612 | -0.0298 | <2e-16 |
| primetype:transtype r i - r t | 0.0 | 0.0080 | 5785.1 | -3.42 | -0.0432 | -0.0117 | 6e-04 |
| primetype:transtype r i - u t | 0.0 | 0.0080 | 5793.9 | -5.66 | -0.0612 | -0.0297 | <2e-16 |
| primetype:transtype u i - r t | 0.0 | 0.0081 | 5793.1 | 2.24 | 0.0022 | 0.0338 | 0.025 |
| primetype:transtype u i - u t | 0.0 | 0.0080 | 5785.8 | 0.00 | -0.0157 | 0.0157 | 0.999 |
| primetype:transtype r t - u t | 0.0 | 0.0081 | 5793.2 | -2.23 | -0.0338 | -0.0022 | 0.026 |

Note: Std. Error = Standard Error; DF = Degrees of Freedom; CI = Confidence Interval