How Number of Errors and Location of Errors in Spelling Impede Reading Performance in Undergraduate Students

BY

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Abstract

The Lexical Quality Hypothesis (LQH) suggests that words are stored in memory as orthographic representations which consist of their meaning, spelling, and phonology, and errors in any of these areas lowers the quality of these representations, resulting in slower, more effortful retrieval from memory. Consequently, spelling accuracy has been shown to directly relate to reading speed, as spelling accuracy reflects lexical quality. Here, 75 undergraduate students spelled 25 words over three attempts to determine spelling accuracy, and then read these same words aloud, and their reading times were recorded. In support of the LQH, words with low and intermediate spelling accuracy were read significantly slower than words with high spelling accuracy. The location of first spelling errors and the number of spelling errors within misspelled words were also evaluated in relation to reading speed. Words with errors located in the first half were read significantly slower than words with errors located in the second half of the word. This supports scanning theory and the cohort model- which suggest that we store and retrieve words from left to right, and process them in real-time. Furthermore, the number of errors in the spelling of a word was positively correlated with reading speed. In conclusion, spelling accuracy as well as location and number of spelling errors within a word significantly hamper reading speed for these same words. These findings have significant implications for theory and educational settings.

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How Number of Errors and Location of Errors in Spelling Impede Reading Performance in Undergraduate Students

Spelling and reading are crucial in all aspects of one's life, from communicating with others to excelling in one's professional career. These two skills seemingly go hand in hand and past research has found a strong correlation between spelling and reading skills (Burt, 2006). Furthermore, it has been found that one's own spelling accuracy influences reading speed (Martin-Chang et al., 2014; Ouellette et al., 2017; Rossi et al., 2019). While these skills appear fairly effortless by adulthood, there are many processes underlying reading and spelling that are relatively unknown, such as exactly how specific weaknesses in the spelling process may impede word level reading. The current study focuses on how spelling ability, as indicated through spelling accuracy, influences word reading performance, as measured through reading speed. Specifically, the location of a spelling error and the number of errors in a participant's spelling was observed in relation to their influence on reading speed for those same words.

Orthographic Representations

The lexical quality hypothesis (LQH) suggests that as reading and writing experience increases, printed words are stored in memory as lexical representations and are retrieved based on a combination of three necessary properties: phonology (i.e., the way they sound), semantics (i.e., their meaning) and orthography (i.e., their spelling) (Perfetti, 2007; Rosenthal & Ehri, 2011). These representations can be consistently and accurately stored in memory, and therefore deemed as being of high lexical quality, indicating a combination of proper pronunciation, spelling, and meaning. Contrarily, words that are inaccurately stored (i.e., containing errors in phonology, semantic,

orthography, or a combination) are deemed to be of lower lexical quality. A high-quality representation allows the reader to access and retrieve it efficiently from memory, whereas a lower quality lexical representation would be at a disadvantage for access and retrieval, as it may lead the reader to a number of close matches and/or delay activation, resulting in more effortful and slower processing (Perfetti et al., 2003). Further, this more effortful process of retrieval can be explained by the visual mismatch between a printed word and the corresponding orthographic representation in memory (Martin-Chang et al., 2014). Orthographic representations are word-specific, meaning a reader may have fully-specified orthographic representations for some words, and underspecified for others (Perfetti, 2007).When the stored orthographic information is not a perfect match with the printed word, lexical access and retrieval are proposed to be negatively impacted (Ouellette et al., 2017).

Hence, the LQH proposes that more advanced readers, as shown through their fluency and pronunciation, have better quality representations of words stored in memory (Andrews & Bond, 2008; Perfetti, 2007). It has also been found that high frequency words (more common) are more likely to have high quality representations than low frequency words, showing evidence for the benefits of experiential repetition (Perfetti, 2007). Perfetti (2007) suggested that skilled readers have more experience with words in general, are more likely to experience the merits of repetition, and therefore have more high-quality stored words than a lower ability reader with less experience.

Effect of Spelling Errors on Reading

Martin-Chang et al. (2014) were amongst the first to directly examine how the quality of orthographic representations affects reading speed. They built upon studies by

Perfetti (1992; 1998) that suggested that spelling a word accurately one time did not equate to lexical quality, and therefore tested participants' spelling for words over five trials to additionally explore the effects of the stability of orthographic representations on reading. Martin-Chang et al. also tested reading speed for these same words. They hypothesized that since a word with a lower quality lexical representation, as indexed by spelling accuracy and stability, is retrieved more effortfully, then the reading speed of that word would be negatively impacted. Undergraduate students with expected levels of reading and spelling, as determined through standardized tests, were given reading and spelling tests on 30 target words (which consisted of 10 very difficult to spell, 10 moderately difficult, and 10 easy to spell words). The results of the study indicated that words that were always spelled correctly (i.e., high accuracy) had a reading speed advantage over words that were never spelled correctly (i.e., low accuracy). Furthermore, the more stable the word was spelled, as indicated by always being spelled correctly over the trials, the faster the word was read, in contrast to words that were spelled inconsistently over trials (i.e., unstable). A within-word analysis found that individuals read the words that they spelled with high accuracy faster than the words that they did not, demonstrating that orthographic representations of words can vary within individuals. This study provides evidence that inaccurate and unstable spelling might not hinder reading entirely, but may come with a latency cost to the reader, and additionally, that correct reading is not necessarily indicative of high spelling accuracy.

To further this research, Ouellette et al. (2017) tested individual differences in reading and spelling abilities within an experimental design. They explored the possibility of increasing spelling abilities in undergraduate students by providing training

for words that were determined to be difficult to spell prior to the experiment. Additionally, they examined if this spelling training would translate into increased reading speed for these same words. Participants were initially tested for spelling ability with multisyllabic words, and then the words misspelled by each participant were randomly assigned to one of two conditions: a control condition in which aspects of word meaning were taught (with no spelling practice) and a training condition in which participants practiced spelling the words as well. After the two experimental conditions, participants completed a spelling and word reading test to measure spelling accuracy and reading speed. In line with findings from Martin-Chang et al. (2014), it was found that participants read words that were consistently spelled (stable) 20% faster than words they inconsistently spelled (unstable) (Ouellette et al., 2017). Furthermore, the training condition was effective in improving the overall spelling abilities of the participants on the difficult target words, and consequently increased reading speed of the improved words, demonstrating that there was a direct, causal positive relationship between spelling ability and reading speed.

Additionally, Conrad (2008) found that spelling practice led to higher quality orthographic representations and improvements in reading in children. In this study, grade two English speaking students practiced spelling and reading a list of 40 non-words, and then were tested for spelling and reading with these same nonwords. Spelling accuracy was determined based on the presence of an error (correctly spelled or incorrectly spelled) and reading ability was determined based on whether it was correctly pronounced or not. The significant increase in both spelling and reading after practice indicated the nature of how we practice leads to improvements within that same area (i.e.,

reading practice improves reading; spelling practice improves spelling); moreover, spelling practice was found to benefit reading, more so than reading practice /benefited spelling. This again, demonstrates how spelling reflects the quality of orthographic representation and has a direct impact on our reading fluency.

While high- and low-quality orthographic representations have been studied, it remains unclear if these points were positioned on a continuum. Recall that readers may not only have accurate orthographic representations (i.e., words that are always spelled correctly), and inaccurate representations (i.e., always spelled incorrectly) but also inconsistent (i.e., spelled differently across attempts). When the spelling of a word is inconsistent, it is said to have a less stable representation, and therefore considered to be of intermediate quality. Similar to past studies, Rossi et al. (2019) tested 90 teenage participants on word spelling and reading over multiple (three) trials. Consistent with findings by Ouellette et al. (2017) and Martin-Chang et al. (2014), reading speed was positively correlated with spelling accuracy. To reflect spelling accuracy, each word was scored out of 3 (0/3 = never spelled correctly, 1/3 and 2/3 = inconsistently spelled correctly, and 3/3 = always spelled correctly) and significant positive correlations were found between reading speed and consistency of spelling. Furthermore, words with stable spelling (as measured by the number of times the word was spelled the same over attempts) were read faster than words that were spelled differently from one trial to the next, and words that were consistently spelled wrong. This study provides evidence that words with intermediate accuracy as well as stability, have a latency advantage over words with poor accuracy and stability. In general, these findings lend further support to the LQH and suggest that orthographic quality exists on a continuum.

To explore the mechanisms underlying why accuracy and stability in spelling affects reading, Rahmanian and Kuperman (2017) examined words that have frequently misspelled variations. They argued that the more often someone is exposed to spelling errors in a printed word, the more they may unlearn the correct spelling and in turn, their processing of the word may become slower. Every time a word is encountered with a different spelling, it may be simultaneously processed with the other spelling variants, thus leading to more competition among alternatives in lexical selection. Rahmanian and Kuperman (2019) proposed the term *entropy* as a measure of competition between a word's different variations of spelling, where low entropy would be a word with no ambiguity in spelling, and high entropy would be a word with many spelling variants. They used a 7-billion token USENET corpus (word database) to determine the number of spelling variants for each word used in the study (Shaoul & Westbury, 2013). For example, if the word *innocent* was encountered 69% of the time, and 31% of the time incorrectly encountered as *inocent*, this would cause it to have relatively high entropy (Rahmanian & Kuperman, 2019). They predicted that words with high entropy would cause participants to have greater difficulty in learning and recognizing them. To test this hypothesis, undergraduate students were asked to silently read sentences containing 70 correctly spelled target words, and eye movements were tracked to measure fixation on the target word as well as total reading time. As expected, it was found that high frequency words with low entropy (no spelling ambiguity) were read quicker than words with high entropy. Moreover, high frequency words were found to be more sensitive to the effects of entropy due to an increased exposure to the different ways of spelling these words. Finally, the findings indicated that entropy affects all readers equally. These

conclusions lend support to the LQH, and findings by Martin-Chang et al., (2014); Ouellette et al. (2017); Rossi et al. (2019), that the more uncertainty in the spelling of a word, the slower the word will be processed, and therefore result in increased latencies for the reader.

Processing Theories

While the research just reviewed has shown that orthographic quality, as indexed by spelling ability, directly effects reading quality and reading speed, much is still unknown about just how misspellings affect lexical quality. Kwantes and Mewhort (1999) proposed the scanning theory, which suggested that when we encounter words, we store them in memory in first to last order, and in the English language this order is from left to right. Therefore, when we retrieve the word from memory, we retrieve it starting with the first letters. Kwantes and Mewhort (1999) built on the cohort model of speech perception (Marslen-Wilsen & Zwitserlood, 1989) which states that words are processed in real time, and processing starts before the word is finished. In auditory perception, this means that the initial sound of a word activates all possible stored words that start with the same phonology. As further sounds are processed, this cohort of possible matches is reduced, until only one word remains. In printed word recognition, the scanning theory proposes a similar process occurs, and the position of the letter that distinguishes the target word from other words in its cohort is the orthographic unique point (OUP) (Kwantes & Mewhort, 1999). The OUP is found in English when processing the word from left to right, and can either be early or late in a word. For example, as the word *shell* is processed from left to right, it could have a cohort of she, she's, shelter, etc. In this case, the OUP would be the fifth letter (late in the word), as it is not until the final letter *l*

that the reader can distinguish the word *shell* from all other words. In contrast, an example of a word with an OUP located at the beginning is the word *silhouette*, where the OUP is located in the 4th spot of the word. To test their hypothesis that the later the OUP in the word, the slower the word would be processed, Kwantes and Mewhort (1999) measured the time it took for undergraduate students to orally read seven letter words using a computerized voice onset. The results of their study confirmed their prediction, indicating that words with an early OUP were read with a latency advantage over words with a late OUP. These findings lend support to the prediction that errors located at the beginning of the word would affect reading speed more than errors located at the end of a word. That is, the effect of lexical quality on reading speed may vary depending on how far into a word the first instance of incorrect orthography is (i.e., how far into a word the participant's first spelling error is located). A similar explanation can be derived from earlier work by Coltheart and Rastle (1994), who identified spelling irregularities as words with spelling that cannot be relied on for its pronunciation (e.g., Colonel would be pronounced col-on-el based-on appearance, therefore making it irregular). They defined the term 'exception words' as words with irregularities and words without irregularities, such as the word *sound*, were considered to be 'regular words'. To determine how irregularities affect reading latencies, they measured reading time by participants, using a computerized voice key when presented with 96 exception words and 96 regular words. Additionally, the irregularities in exception words were located in letters 1 through to 5 of the word. They found that words with irregularities early in the word had more of a detrimental effect on reading speed, since the word is processed from left to right. It would seem reasonable then to hypothesize that this effect would also transfer to lexical

quality as indexed by spelling errors, where errors located earlier in the word would slow reading more than later in the word. This contention has yet to be directly studied, however.

One question encountered when studying the effects of spelling on reading is, if there exists a strong correlation between spelling ability and reading ability, then what accounts for 'unexpectedly poor spellers'? Meaning those who are able to read fluently despite being poor spellers (Frith, 1985). One way to explain these instances can be attributed to partial cue reading, which refers to readers who use small phonological letter strings, often located at the beginning or the end of a printed word, as well as semantics to decode the word. For example, the word *absence*, stored as ab???ce in memory, could still be read by using partial cue reading (looking at the letters *ab* and *ce),* especially if found in a sentence providing context. This is particularly true in longer words since a missing or inaccurate letter would not have as much weight to the spelling as one letter of a shorter word would have (Holmes & Castles, 2001). Homes and Carruthers (1998) suggested that although partial cue reading may be sufficient for adequate reading, it is not sufficient for proper spelling. This could be explained due to the fact that in reading, the word is already visually presented but in spelling the word's orthography must be generated (Conrad, 2008).

In support of this, Burt (1996) presented participants in two groups (classified as either poor spellers or good spellers) with sentences containing target words that had a homophone, and sentences containing the homophone of the proper target word. The poor spelling group often identified sentences containing the homophone of the target word as correct, providing evidence of partial cue reading as they had not processed

every letter. Moreover, while partial cue reading may be useful for reading, it still may hamper lexical retrieval and consequently reading speed. Holmes and Carruthers (1998) had good and unexpectedly bad spellers make lexical decision tasks and orthographic tasks (designed to make quick judgements and therefore prevent the influence of memory) and while both groups were equally as accurate, the good spellers completed the task significantly faster than the unexpectedly bad spellers.

These findings on partial cue reading lend support to both hypotheses in the current study. First, if the reader is processing the word from left to right and only relying on some of the letters of the word to read it, then it would reason that errors in spelling located in the beginning of the word would have greater impact on lexical retrieval and hence reading speed. Second, the more errors that are located in the spelling of the word, the lower the lexical quality, causing the reader to have fewer accurate cues to read from (i.e., match to their stored representation), and therefore slowing the retrieval and reading of the word even more.

Current Study

While past research has shed light on how orthographic quality, as measured through spelling accuracy and stability, influences reading speed, there are still unanswered questions surrounding the underlying orthographic mechanisms that affect reading. The current study is among the first to examine how the number and location of errors in an individual's spelling of a word impacts the reading of that same word. The current study replicated research by Martin-Chang et al. (2014) and Ouellette et al. (2017), which directly tested the spelling-reading speed interaction, and extended that research in examining error location and the impact of number of errors within

misspelled words on reading speed.

The current study incorporated two novel hypotheses. The first hypothesis addressed how the location of a spelling error in the written word impedes reading performance. Based on scanning theory and the cohort model, it was predicted that errors located in the first half of the word would hinder the reader's speed more than in the second half, since in English words are processed from left to right, and retrieved similarly as a result. Errors located at the beginning of the word result in more difficulty in retrieval and thus have a negative effect on reading speed. When taking into consideration the lexical quality hypothesis, the second hypothesis predicted that the more errors made in the spelling of a word, therefore reflecting lower lexical quality, would cause the reader to spend more time reading the word, due to more effort needed for retrieval. In other words, the second hypothesis expected to see a direct correlational relationship between the number of errors in a written word and the speed at which it was read.

Methods

Participants

From the study by Wheaton (2019), 75 undergraduate students enrolled in an introductory psychology class at a small university in Eastern Canada were recruited through SONA and received 1% course credit for their participation. Two participants were removed from analysis because they were missing testing data (n=73). Most were female (72%) and the mean age was 20 years old. All participants indicated that English was their first language, with 76% speaking only English and 15% speaking English and French, and the remainder speaking English and another language from birth. One

participant did not report their language. All participants scored within two standard deviations on the TOWRE-2 subtest and the WJ-III spelling subtest making their scores on reading and spelling within the expected range for their education and age.

Materials

Materials are from Wheaton (2019). The Woodcock Johnson Test of Achievement- Third Edition (WJ-111; Woodcock et al., 2001) was used to test individual spelling ability and the Test of Word Reading Efficiency- Second Edition (TOWRE-2; Torgeson et al., 2021) was incorporated to assess participants' reading ability.

For the WJ-III portion of the study (items 36-59), the researcher dictated 24 words that each participant was asked to write down with pen and lined paper, and dictation was stopped after six consecutive words had been incorrectly spelled. These words were selected from a field of 59 words, based on expected college level spelling ability.

The TOWRE-2 portion of the study consisted of two parts. First, the participants completed a sight-word efficiency subset, where they were told to read as many words as possible in 45 seconds, to a maximum of 108 words, in order to assess the quality of orthographic representations held by the participant. Secondly, for the Phoneme Efficiency subset, participants were asked to read as many non-words out loud as possible from a list of 66, also with 45 second time limit. This second subtest was designed to test the participants' phonemic reading ability.

Finally, the participants were asked to read and spell words from an experimental word list containing 25 words, some of which were taken from Rossi et al. (2019) and additionally some words which were selected to add variety to word length and difficulty of spelling. (See Appendix).

Procedure

The procedure is from Wheaton (2019), which recruited undergraduate students through SONA and then were asked to join the researcher individually in the Language and Literacy Lab for the study. Participants were first asked to read and sign a consent form confirming their voluntary consent to take part in the study and then were given a short questionnaire asking demographic questions. Next the researcher dictated the 24 words to the participants as part of the WJ-III test of spelling, and the participant wrote down the words on a lined sheet of paper with a pen. This was followed by the TOWRE-2 portion of the study, starting with the subset of sight word efficiency, participants were instructed to read as many words as possible from a list of 108 in 45 seconds. Before testing began, participants were allowed a practice trial of 8 words. The Phonemic efficiency subset of the TOWRE-2 was then administered, after another practice trial of 8 non-words. During this subset, participants read as many non-words as possible in 45 seconds from a list of 66. For both subsets, the researcher began timing when the participant said the first word and ended at the 45 second mark. The experimental word list portion of the study was then given, which consisted of having participants spell the 25 words (see appendix) dictated by the researcher, with pen and lined paper. The same words were presented three times (for a total of 75 attempts) and the words were presented in random order over the three occurrences. A new sheet of paper was provided to participants between each set of 25 words with a number at the top, to prevent participants from comparing to previous spellings. For the experimental reading task, participants were instructed to move to the computer and were centrally presented with a + on the computer screen to orient their attention. They were instructed to verbally read

each word as accurately and clearly as possible into a microphone attached to a Cedrus SV-1 voice key. The same 25 words as used in the spelling task were presented one at a time using SuperLab 5.0, with a fixation point (+) presented between each word for 1000ms. The researcher pressed one of three keys after every attempt indicating a correct reading, improper reading, or an issue with the Cedrus SV-1 voice key. Similar to the spelling task, all 25 words were presented three times each in random order. Finally, participants were debriefed about the purpose of the study and how the data would be used.

Results

Before conducting analyses, reading times that were coded as an error were removed from the data set, and any reading times coded as correct that were below 100 ms or above 3000 ms were considered outliers. Seven data points exceeding 3000 ms were removed as outliers. As such, the data reported here are only for instances where a word was read correctly and within an appropriate time window.

As presented in Table 1, there were significant correlations amongst all pre-test literacy measures. Scores on both of the TOWRE-2 subtests and the WJ-III were significantly positively correlated, indicating that spelling accuracy is directly related to non-word decoding and word reading overall. Additionally, mean reading time was significantly negatively correlated with scores on the WJ-III and both TOWRE-2 subtests, such that higher standardized spelling and reading scores were associated with faster reading speed on the experimental words.

To evaluate the effect of spelling accuracy on reading speed on a word-by-word basis, each participants' spelling accuracy was calculated for each word (25 words) out of

three attempts. Words that were spelled correctly over all three attempts (3/3) were determined to have high accuracy, words that were spelled correctly once or twice over three attempts (1/3;2/3) were deemed to have intermediate accuracy, and words never spelled correctly (0/3) were deemed low accuracy. Words spelled correctly one and two times were combined due to lower incidences of words in those categories. A repeated measures analysis of variance (ANOVA) was conducted to assess whether there were differences in reading speed of words as a function of these spelling accuracy classifications. Mauchly's test of sphericity was significant ($p<.001$), therefore the Huynh-Feldt adjustment was used. The analysis determined that mean reading speeds differed significantly depending on spelling accuracy, and a large effect size was found, $F(2,71)=13.628$, $p<.001$, $\eta_2=.277$. Bonferroni's post hoc test was used to establish which categories of spelling accuracy differed significantly in reading speed. As presented in Figure 1, there was a significant difference (all p's $\leq.002$) between all comparisons.

To examine whether the location of the first spelling error within a word impacts reading speed for that word, spelling errors were coded with respect to their position within each word, and mean reading speed was calculated for each participant for words where the misspelling occurred in the first half of the word and for words that had the first misspelling in the latter half of the word. A repeated measures ANOVA was used to test whether there was a significant difference in reading speed for words where the first spelling error was located in the first half of the word, versus words where the first error was located in the second half. Error location was determined by dividing the first error by total number of letters in the word. For example, if the word "hemorrhage" was spelled "hemmorrage", the first error location would be four, divided by 11 (the total

number of letters in the word), producing an error location of .364, indicating that the error was located in the first half of the word. As shown in Figure 2, the analysis determined that there was a statistically significant difference between mean reading times for words with errors located in the first half of the word (M=676.41, SD=136.45), compared to words with errors in the second half (M=643.52, SD=118.40); $F(1,72)=18.956$, $p<.001$, $\eta_2=.208$. Therefore, words with errors located in the first half of the word were read significantly slower than words with errors located in the second half, with a medium effect size.

Table 1

Mean, SD, and Intercorrelations for Literacy Measures (n=73)

Variable	1	2	3	4
1. TOWRE-2 Words				
2. TOWRE-2 Non-Words	.588**			
3. WJ-III	.360**	.562**		
4. Mean Reading Time (ms)	-.432**	-.419**	-.365**	
Mean	106.70	110.45	50.99	659.97
SD	12.99	12.81	4.55	123.60

Note. ** indicates $p<.001$. Mean reading times were calculated by taking the average time in milliseconds it took for participants to read words from each measure.

It was also of interest to determine whether there was a correlation between the number of spelling errors in a word and the speed at which that word was read. The number of spelling errors per word was determined by calculating how many letters were incorrectly written within its spelling. For example, if the word “hooligan” was spelled

"ho**l**lig**g**an", then the word would have two misspellings. The mean number of errors per word was *M*=1.92 (*SD*=.389), and the number of errors ranged from 1 to 8. Additionally, the majority of participants misspelled words with three or fewer errors (90% of misspellings). There was a significant positive, correlation found between participants' number of spelling errors per word and their mean reading speed for the words they misspelled, *r*=.250, *p*=.034, indicating that as number of errors increased, so did the amount of time that it took to read that word.

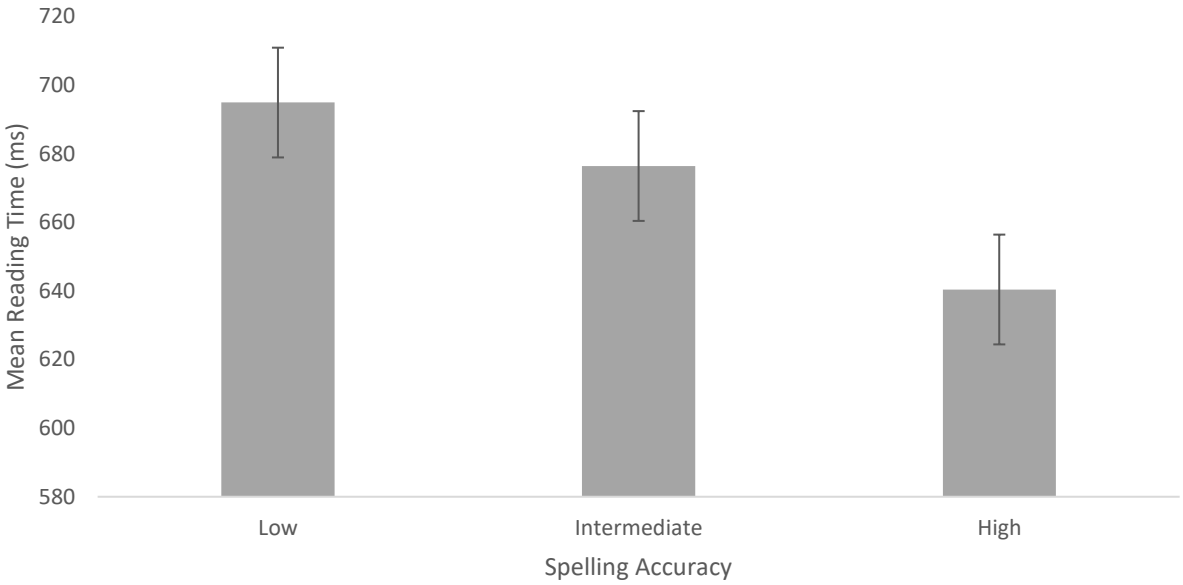

Figure 1. Differences in mean reading time (ms) by category of spelling accuracy (*n*=73). Error bars for all figures represent standard error.

Discussion

The current study incorporated two hypotheses to further understand the relationship between spelling accuracy and reading speed. The first hypothesis predicted that words with first spelling errors located at the beginning of the word would slow reading speed more than words with first errors located in the second half, and this

hypothesis was supported. The second hypothesis expected that the more errors located in the spelling of a word, the slower that word would be read. This hypothesis was also supported. Some possible explanations, implications, and directions for future studies will be discussed further.

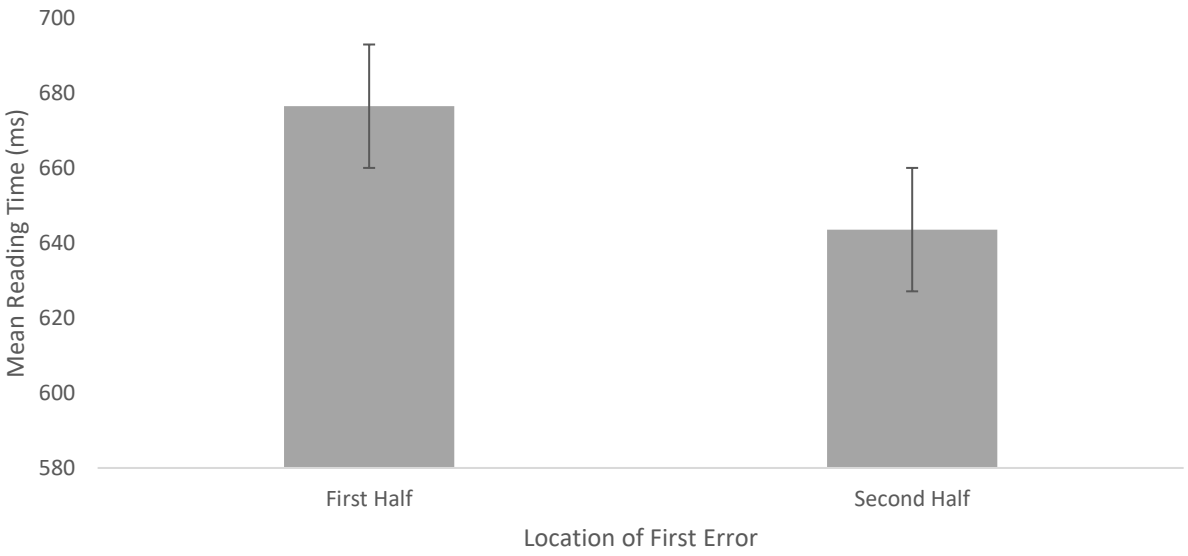

Figure 2. Differences in mean reading time (ms) by location of first spelling error (*n*=73).

Spelling Accuracy

The relationship between spelling ability and reading performance was examined to determine how one influences the other. Reading time for participants was measured using a computer program, and spelling ability was measured through a spelling test of 25 words, over three spelling attempts for each word. This design was based on recommendations by Perfetti (1992;1998) that suggest that spelling a word accurately one time does not equate to lexical quality. Studies by Martin-Chang et al. (2014), Ouellette et al. (2017) and Rossi et al. (2019) which directly tested the spelling-reading speed interaction were replicated, demonstrating that words with high accuracy (always spelled correctly) are read significantly faster than words with intermediate (sometimes spelled

correctly) and low accuracy (never spelled correctly), since these words are stored with reduced lexical quality in memory, therefore causing more effortful retrieval. This difficulty in retrieval can be explained by the Lexical Quality Hypothesis (LQH), which proposes that words are stored and retrieved as lexical representations in memory based on a combination of their phonology, semantics, and orthography. Therefore, errors in one or a combination of these properties lower the overall lexical quality of the word, resulting in slower, more effortful processing (Perfetti et al., 2003). Additionally, words with low orthographic quality have a visual mismatch with their correct version, further hampering lexical access and retrieval (Ouellette et al., 2017).

Here, words were considered to have high accuracy when the participant spelled them correctly over all three attempts (3/3 correct spelling attempts), they had intermediate quality when they were spelled differently over attempts (1/3;2/3 correct spelling attempts), and had low accuracy when spelled incorrectly over all three attempts (0/3 correct spelling attempts). Consistent with past research findings, the results from the current study indicated significant differences between all three accuracy classifications, such that participants read accurately spelled words faster than inconsistently spelled words, and inconsistently spelled words faster than words they always spelled incorrectly. This study provides further evidence that the accuracy of a single word spelling has a direct influence on reading speed for that same word. In general, these findings lend support to the LQH, since spelling accuracy is seen as a direct measure of the quality of stored word in memory. Additionally, these findings support Rossi et al.'s (2019) conclusion that orthographic quality exists on a continuum, meaning that words with high lexical quality have an advantage over both intermediate quality and low

quality, and intermediate quality representations are processed faster than lower ones.

Error Location

The current study incorporated two novel hypotheses. The first hypothesis expected that based on scanning theory and the cohort model, words with spelling errors located in the first half of the word would be read slower than words with spelling errors located in the second half of the word. The results support this hypothesis, indicating that the reader has a more difficult time reading words with early errors, as they were read significantly slower. This supports the scanning theory proposed by Kwantes and Mewhort (1999) that suggested that when we encounter words, we store them in first to last order (left to right), and therefore retrieve them in the same manner. In this respect, if there are errors located in the first half of the word, the retrieval process is interrupted before the reader has enough information to successfully recognize the word, resulting in more effortful, slower processing, causing reading latencies. This builds on the cohort model of speech perception which suggests that words are processed in real time, beginning before the word is finished (Marlslen-Wilsen & Zwitserlood, 1989). In printed word recognition, this means that every letter processed from left to right may activate all possible matches for the word until only one word remains. In this case, errors located earlier in the word would be more detrimental as they would interrupt the reading process earlier and slow the reading of the word that much more. Additionally, Coltheart and Rastle (1994) found a similar effect in words that have spelling irregularities located at the beginning of the word compared to at the end.

One note about the current study is that only the location of the first spelling error was examined. Since many words that contained spelling errors had more than one error,

it would be of interest to further explore how reading speed is influenced when considering the location of all spelling errors. For example, does one spelling error located in the first half of the word slow reading more than two errors located in the second half of the word? Future studies should evaluate the influence of all errors on reading speed and how this may interact with the number of errors within a given spelling.

Partial Cue Reading

This study provides direct evidence for partial cue reading, since participants were able to read the words that they were unable to spell correctly. Partial cue reading occurs when the reader uses phonological letter strings (usually from the beginning or end of the word), as well as semantics to decode the word. It was observed that words with spelling errors were still able to be read by participants (although significantly slower). Homes and Carruthers (1998) suggested that although partial cue reading may be sufficient for adequate reading, it is not sufficient for proper spelling. This could be explained due to the fact that in reading, the word is already visually presented but in spelling the word must be generated (Conrad, 2008). In the present study, words were presented without context, therefore participants were unable to decode the word with the use of semantics yet were still able to read words they could not spell. This finding provides further evidence that participants were likely using partial cues to recognize the words, and since the reader is using partial cues instead of fully formed, high quality orthographic representations for word retrieval, reading is significantly impacted. Finally, partial cue reading could also account for ‘unexpectedly poor spellers’, those who are able to read fluently, but do not spell accurately (Frith 1980;1985). Since the participants in this study

are all at undergraduate level and have been deemed to have standard levels of spelling and reading ability (by the standardized tests taken prior to the experiment), it has been made clear that although the participants can still read a word (although significantly slower), they may not be able to spell it.

Number of Errors

The second hypothesis predicted that the number of errors located in the spelling of a single word would be positively correlated with reading time for that same word, since the quality of the orthographic representation would be reduced with every error. Data analysis was conducted, and a significant and positive correlation between number of errors and reading time was found, therefore supporting this hypothesis. This study is one of the first to examine how the number of spelling errors located in a single word influences reading of that same word. The finding is not surprising, since orthographic quality has been consistently found to influence reading speed, and the number of errors can be seen as a direct measure of this (Martin-Chang et al. (2014); Ouellette et al. (2017); Rossi et al. (2019)). While this correlational result sheds added light onto the mechanisms influencing reading speed, future studies should further examine how the number of errors in a word impacts reading speed by looking directly at differences between how many errors one has in their spelling of a word, and how quickly it is read. For example, are there significant differences in reading speed between words with one, two, or three errors in spelling?

Conclusion

Consistent with past findings, spelling ability as measured through spelling accuracy, has a direct impact on reading speed on a word-by-word basis. This study

further demonstrated that the location of spelling errors, and the number of spelling errors both also play a role in reading speed of the same word. These findings have implications for real-world settings such as in educational settings, and in the workplace. If one's reading is being hampered by spelling ability, they may fall behind in school or have difficulties successfully navigating their career. In an educational setting, students who are struggling to read may benefit from a more in-depth assessment of spelling ability. Ouellette et al. (2017) demonstrated that undergraduate students who were given spelling training were successful in improving their spelling accuracy, which then translated to faster reading speed. Similar findings were demonstrated by Conrad (2008) who provided reading and spelling practice for grade two students, which consequently yielded significant improvements in both areas. Moreover, it was found that spelling practice improved reading ability more than reading practice improved spelling ability. Overall, it may be concluded that individuals who are having trouble with reading fluency may benefit from spelling practice and training as a route to improving overall lexical quality.

References

Andrews, S., & Bond, R. (2008). Lexical expertise and reading skill: bottom-up and top-down processing of lexical ambiguity. *Reading and Writing, 22*(6), 687–711. https://doi.org/10.1007/s11145-008-9137-7

Burt, J. S., & Tate, H. (2002). Does a reading lexicon provide orthographic representations for spelling? *Journal of Memory and Language, 46*(3), 518–543. https://doi.org/10.1006/jmla.2001.2818

Burt, J. S. (1996). Spelling in adults: orthographic transparency, learning new letter strings and reading accuracy. *European Journal of Cognitive Psychology, 8*(1), 3–44. https://doi.org/10.1080/095414496383194

Burt, J. S. (2006). What is orthographic processing skill and how does it relate to word identification in reading? *Journal of Research in Reading, 29*(4), 400-417. https://doi.org/10.1111/j.1467-9817.2006.00315.x

Conrad, N. J. (2008). From reading to spelling and spelling to reading: Transfer goes both ways. *Journal of Educational Psychology*, *100*(4), 869–878. https://doi.org/10.1037/a0012544

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*(6), 1197–1211. https://doi.org/10.1037/0096-1523.20.6.1197

Frith, U. (1985). The usefulness of the concept of unexpected reading failure: Comments on "Reading retardation revisited." *British Journal of Developmental Psychology, 3*(1), 15–17. https://doi.org/10.1111/j.2044-835X.1985.tb00949.x

Holmes, V. M., & Carruthers, J. (1998). The relation between reading and spelling in skilled adult readers. *Journal of Memory and Language*, *39*(2), 264–289. https://doi.org/10.1006/jmla.1998.2583

Holmes, V. M., & Castles, A. E. (2001). Unexpectedly poor spelling in university students. *Scientific Studies of Reading*, *5*(4), 319–350. https://doi.org/10.1207/s1532799xssr0504_02

Kuperman, V. & Rahmanian, S. (2019) Spelling errors impede recognition of correctly spelled word forms, Scientific Studies of Reading, *23*(1), 24-36**.** https://doi.org/10.1080/10888438.2017.1359274

Kwantes, P. J., & Mewhort, D. J. (1999). Evidence for sequential processing in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(2), 376–381. https://doi.org/10.1037/0096-1523.25.2.376

Marslen-Wilson, W., & Zwitserlood, P. (1989). Accessing spoken words: The importance of word onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *15*(3), 576–585. https://doi.org/10.1037/0096-1523.15.3.576

Martin-Chang, S., Ouellette, G., & Madden, M. (2014). Does poor spelling equate to slow reading? The relationship between reading, spelling, and orthographic quality. *Reading and Writing*, *27*(8), 1485–1505. https://doi.org/10.1007/s11145-014-9502-7

Ouellette, G., Martin-Chang, S., & Rossi, M. (2017). Learning from our mistakes: improvements in spelling lead to gains in reading speed. *Scientific Studies of Reading*, *21*(4), 350–357. https://doi.org/10.1080/10888438.2017.1306064

Perfetti, C. A. (1998). Two basic questions about reading and learning to read.

Problems and Interventions in Literacy Development, 15–47. https://doi.org/10.1007/978-94-017-2772-3_2

Perfetti, C. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*, *11*(4), 357–383. https://doi.org/10.1080/10888430701530730

Perfetti, C. A., & Hart, L. (2002). The lexical quality hypothesis. *Studies in Written Language and Literacy*, 189–213. https://doi.org/10.1075/swll.11.14per

Perfetti, C. A., Hart, L. A., & Reichle, E. D. (2001). Lexical quality and reading skill. *PsycEXTRA Dataset*. https://doi.org/10.1037/e537102012-598

Rahmanian, S., & Kuperman, V. (2017). Spelling errors impede recognition of correctly spelled word forms. *Scientific Studies of Reading*, *23*(1), 24–36. https://doi.org/10.1080/10888438.2017.1359274

Rosenthal, J., & Ehri, L. C. (2010). Pronouncing new words aloud during the silent reading of text enhances fifth graders' memory for vocabulary words and their spellings. *Reading and Writing*, *24*(8), 921–950. https://doi.org/10.1007/s11145-010-9239-x

Rossi, M., Martin-Chang, S., & Ouellette, G. (2018). Exploring the space between good and poor spelling: orthographic quality and reading speed. *Scientific Studies of Reading*, *23*(2), 192–201. https://doi.org/10.1080/10888438.2018.1508213

Seidenberg, M. S. (2007). Connectionist models of reading. *The Oxford Handbook of Psycholinguistics*, 234–250. https://doi.org/10.1093/oxfordhb/9780198568971.013.0014

Shaoul, C., & Westbury, C. (2013). A reduced redundancy USENET corpus (2005–2011). Edmonton, AB: University of Alberta. Retrieved

from www.psych.ualberta.ca/~westburylab/downloads/usenetcorpus.download.html

Torgeson, J.K., Wagner, R.K., & Rashotte, C.A (2012) *Test of word reading efficiency second edition; Examiner's manual.* Austin, TX: Pro-ed.

Wheaton, C. (2019) The impact of spelling accuracy on reading speed: orthographic quality, error location, and type of error. (Unpublished honours thesis). Mount Allison University, Canada.

Woodcock, R.W., McGrew, K.S., & Mather, N. (2001). *Woodcock-Johnson III test.* Itasca, IL: Riverside.

Appendix A: Experimental Word List

1. Ache
2. Accommodate
3. Annoyed
4. Blizzard
5. Bureaucracy
6. Challenging
7. Connoisseur
8. Decease
9. Deductible
10. Diaphragm
11. Disappear
12. Embarrass
13. Fascinate
14. Fluorescent
15. Foreign
16. Hemorrhage
17. Hooligan
18. Nauseous
19. Pinnacle
20. Plagiarism
21. Recommended
22. Silhouette
23. Toboggan
24. Weird
25. Zucchini