R
eading is a crucial task that is accomplished with relative ease on a daily basis. Once an individual develops into a proficient reader, this becomes an automatic process. This automaticity has been clearly illustrated by results of the classic Stroop Task, which demonstrated that people are unable to see words without decoding them (Stroop, 1935). A widely shared Internet meme referencing a nonexistent study suggests that this automaticity equally applies to both correctly ordered and scrambled text. The meme claims: “Aocdrnmig to a rscheearch at Cnabridge Unervtisy, it deosn’t mtaer in waht oredr the lteers in a wrod are”. This is, however, a hoax. Although stimulus and context effects on reading have been explored, no Cambridge University study has shown that letter position in the words people read is irrelevant for word recognition (Davis, 2003).

The closest findings, and possibly the misinterpreted basis for this claim about scrambled word identification, appear to come from one study. Rawlinson (1976) found that, when participants read passages of text where both the first two and final two letters of words were fixed but the middle letters were randomized, there was very little impact on reading comprehension. In fact, not all participants noticed that many of the words contained scrambled letters. But comprehensibility of the sentence as a whole does not automatically equate to easy comprehension of each individual word. Nor does it assume that speed of processing is unaffected, as is suggested by the aforementioned meme.

Although this “Cambridge study” is not real,
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attempts have been made to explore the factors that influence people’s ability to read manipulated text. Much of this research has focused on the effects of either replacing or removing individual letters in words (e.g., Grainger, Granier, Farioli, Van Asche, & van Heuven, 2006; Rayner & Kaiser, 1975) or of transposing letters (e.g., Christianson, Johnson, & Rayner, 2005; Perea & Lupker, 2003) rather than truly scrambling the text. These studies generally had the larger objective of validating a range of models of word identification. The goal of the present research was to examine the effect of both alteration type and prior sentence context on scrambled word identification.

The Influence of Text Alteration on Word Processing

In addition to people’s ability to read words that have been altered (Rawlinson, 1976), a range of priming studies have demonstrated that individuals are influenced by exposure to words with transpositions (created by flipping letter positions) even if they are not explicitly aware of their presentation. Perea and Lupker (2004) asked participants to complete a lexical decision task following a prime. They presented participants with a lowercase prime for 50 milliseconds (that the readers were unaware of seeing) followed by the target word in all capitals. The primes were the exact target (e.g., candle for the target CANDLE), had one letter replaced (e.g., candge), had a transposition at positions three and five (e.g., caldne), or had a double substitution in those positions (e.g., candge). Reaction times on the lexical decision task were faster for the transposition prime than for the double substitution prime but only when consonants (but not vowels) were manipulated. This suggests that words with transpositions activate their base word to a greater degree than do two-letter different nonwords. This same effect can be seen for semantically related primes. When priming the semantically related word light, words with an internal transposition (e.g., heavy for heavy) were more effective primes than words with replacements (e.g., heavy; Perea & Lupker, 2003).

Edited primes also influence reaction times when some of the letters are missing entirely. Grainger et al. (2006) primed target words in a lexical decision task with edited versions of the target. Instead of transposing letters, individual letters were replaced with dashes or were completely removed. For example, the word apricot was preceded by the prime a-ric-t or arict. Both primes led to shorter reaction times than a completed unrelated prime. This was even the case when the dashes were in the wrong location such as in ar-i-c-t. The ability of briefly presented words with alterations to prime a target word demonstrates that a word does not have to be presented in its original, fully accurate form in order for the reader to be influenced by it.

When alterations are made to written text, the specific location of the change is critical for word identification. For example, transpositions occurring across morphemes are less beneficial primes than those where the transpositions occur within a morpheme (e.g., sunshine vs. sunhsine, Christianson et al., 2005). A prime created by crossing the boundary between the two halves of a compound word is no more beneficial than a prime created by substituting letters (e.g., subsbine). This effect, however, is not always replicated (Rueckl & Rimzhim, 2011; Sánchez-Gutiérrez & Rastle, 2013). Duñabiitia, Perea, and Carreiras (2014) argued that the discrepancy in the literature might be explained by differences in reading speed. They found that cross morpheme transpositions slowed reaction times for faster than average readers, but that there was no difference for slower than average readers. They argued that faster readers may use a slightly different strategy for word recognition than do slower readers.

In the context of straight reading tasks, rather than priming tasks, the beginning of a word has been shown to be particularly important. Rayner, White, Johnson, & Liversedge (2006) recorded reading times for sentences where the content words had letter transpositions such that the order of two adjacent letters were reversed. They found that transpositions that occur at the beginning of a word (e.g., osOLVE for solve) were more problematic than those that occur in the middle of a word (e.g., slowe) or end of a word (e.g., soler). Although people may be able to read text with transposed letters, this does not occur without a cost to speed of processing (as was erroneously suggested by the fake “Cambridge Study”). A similar outcome occurs when letters are entirely replaced (Rayner & Kaiser, 1975). These findings suggest that the beginning of a word provides more critical information for word identification than does the middle or the end of the word. This is supported by the finding that the initial letters of a word are the easiest to recognize after short presentation durations (Adelman, Marquis, & Sabatos-DeVito, 2010).

Although the beginning of a word is important for identification, some evidence has also suggested that the end of a word may hold a privileged
position in word identification. In a semantically related priming task, Perea & Lupker (2003) found that, although internal transpositions (e.g., heway for heavy) primed a target word, end transpositions (e.g., heawy) did not. In this context, words with end position transpositions failed to activate semantically related words. Evidence for the relative importance of both the beginning and end of a word comes from a letter identification task. McCusker, Gough, and Bias (1981) presented participants with four-letter words and were cued to name a single letter in the word. The two internal or two external letters appeared 50 milliseconds in advance of the rest of the word or all letters appeared simultaneously. When the whole word was presented at once, response times to name individual letters were faster for the external than for the internal letters, suggesting that external letters are easier to detect. Additionally, participants showed greater overall facilitation for the task when the outside letters appeared first than when the internal letters appeared first.

One of the main goals of the word recognition literature is to test the predictions of a range of computational models for word recognition. These mathematical models rely on input from a lexicon (or mental vocabulary) to learn through experience how to recognize words. The models are designed to simulate what is actually happening in the brain when we are exposed to a written word. A strong model, therefore, must be able to account for the fact that a reader may be able to recognize a word even if it is partially occluded (such as by a coffee stain), when an individual letter is missing (such as a spelling error), or even when letters are reordered. For this reason, a simple model that has strict rules about the location of letters in a word is not sufficient. For example, if the letter b is not in the second position of above, such as in the transposed example aboe, then a strict model would never recognize it.

To account for the fact that words with alterations or deletions can activate their primes (Perea & Lupker, 2004), modern computational models have taken a more flexible approach to letter position. Two such models are the sequential encoding regulated by inputs to oscillations within letter units model (SERIOL; Whitney, 2001) and the spatial coding model (Davis, 2010). Both approaches allow for flexibility in letter position. The SERIOL model, for example, does not expect letters to be in a specific position; rather, it recognizes those individual letters based on activation of specific features (i.e., shapes) in each letter (Whitney, 2001). According to the spatial coding model, instead of strictly requiring correct letter position, the location of each letter in a word is seen as having a degree of uncertainty. At the same time, this approach gives priority to the positioning of external letters in a word (Davis, 2010). This allows the model to predict that words where external positions are held constant (i.e., alternations happen within the word rather than at an end) will be seen as more similar to the base word (and thus provide better priming) than those where the external letters are not maintained. Generally, the finding that modifications altering the ordering of letters are more effective primes than those which change the identity of some letters supports models of word identification that do not require specific letter position information and instead allow for some position independence (Perea & Lupker, 2003).

The Role of Syntactic and Semantic Context in Word Processing

Although the studies mentioned previously have generally focused on priming tasks, words are rarely encountered singularly and instead are read, or heard, within the context of a sentence. All well-formed sentences meet a set of linguistic rules. For example, the sentence, “The cat chased the white rat,” is syntactically acceptable because it follows the rules for the appropriate arrangement of words. It also makes sense semantically because the individual words come together to make a meaningful whole.

The syntactic and semantic contexts that the preceding words in a sentence create can influence the perception of an individual word by building up a set of expectations about what is to come next. This expectation effect has been shown to facilitate spoken word recognition (Miller, Heise, & Lichten, 1951; Miller & Isard, 1963). There are also effects of different levels of acceptability in reading. For example, sentences that conform to “canonical” word order of a language elicit faster responses than those that employ an acceptable, but less common, word order (Tanaka, Tamaoka, & Sakai, 2007).

One way that a sentence’s syntactic context influences word identification is that the sentence stem determines what types of words are allowable. For example, after the stem “The girl drank the,” the word lemonade is both syntactically and semantically appropriate, but the word sleeping is not possible. The frame provides a situation in which a noun is expected (or possibly an adjective before
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a noun). Wright and Garret (1984) examined how these expectations influence speed of word identification. Participants saw sentence fragments with a final word as the target for a lexical decision task. The final word was either a verb or a plural noun and either did or did not fit into the preceding context. They found that reaction times were faster for the syntactically acceptable endings (e.g., “The man spoke but could not COMPETE” or “Just at the time of ENTRIES”) than for the syntactically illegal endings (e.g., “The man spoke but could not ENTRIES” or “Just at the time of COMPETE”). The same results have been found in a word naming task (West & Stanovich, 1986). This demonstrates that when people read an individual word in a sentence, they are influenced by the expectations from the syntactic context such that it is easier to process words that would be possible in that situation.

Although a range of words may be syntactically possible at the end of a sentence stem, some options are privileged. For example, although “The boy enjoyed eating the earthworm” is possible and acceptable, it is much less expected than “The boy enjoyed eating the chocolate.” In this way, the semantic information in the situation can help to constrain the possible upcoming words. Schwanenflugel and Shoben (1985) presented participants with sentences that concluded with either a highly expected word or an unexpected, but semantically related, word. Words that fit the expectation were processed more quickly than the less expected (but just as acceptable) words. Evidence from electroencephalography (EEG) studies has also shown that listeners are able to use sentence context to predict upcoming words. An EEG records event-related potential (ERPs), which measures brain activity in response to a stimulus. When listeners are exposed to an unexpected stimulus, they experience a larger N400 (a negatively polarized ERP 400 milliseconds after stimulus onset) than they do for an expected stimulus. Van Berkum, Brown, Zwerkerood, Kooijman, and Hagoort (2005) examined whether an N400 effect could be elicited even before listeners heard an unexpected word. Because nouns in Dutch have a fixed grammatical gender, any associated adjective must have the appropriate gender markings. Van Berkum and colleagues exposed listeners to sentences that strongly predicted an upcoming noun, but which were preceded by an adjective that either did or did not have the appropriate grammatical markings. An N400 effect occurred when hearing an adjective that did not match the gender for the predicted word. This indicates that, by the time the adjective was heard, the brain had already guessed what the upcoming noun would be and was surprised by the incongruent gender of the adjective.

The Present Studies

In the present research, participants were asked to determine the identity of a scrambled word located at the end of a sentence. This design allows for easy manipulation of a range of factors that may influence a reader’s ability to complete the task. Our goal was to explore two factors that may influence both participants’ overall ability to read scrambled words and the speed at which this occurs. Specifically, we focused on the type of word scrambling and the contextual and predictive power of the sentence in which the scrambled word is found. Although these two broader factors have been explored separately, our goal was to examine these factors simultaneously in a reading task to allow for examination of both their individual effects and how they may interact. Although a reader is generally asked to read a correctly formed word, performance on a scrambled word identification task may help to further explain the processes by which people read. The comparison of manipulations within a target word and in the sentence itself that do and do not harm reading speed and accuracy may help identify the most critical factors for word identification.

The effect of scrambling style was examined in both experiments by comparing the ability of participants to recognize scrambled words when either (a) the first and last letters of the word were held in the correct position with the middle scrambled or (b) when all letters were randomized. This is a stricter version of the manipulation used by Rawlinson (1976) in that it provides significantly less information to the reader because only two, not four, of the letters in the word are held constant. Also, unlike Rawlinson’s study, we focused on accuracy and speed rather than overall comprehension. Studies using letter transpositions and letter replacements have shown that the beginning of a word may provide more crucial information for word identification than the middle or the end of the word (Perea & Lupker, 2003; Rayner & Kaiser, 1975; Rayner et al., 2006). Although previous studies have mostly focused on the importance of having both of the first two letters of the word in the correct order, we only held the first letter constant. Our goal was to explore whether the correct position of the first letter alone, in conjunction with proper
placement of the final letter, would significantly impact participants’ ability to decode scrambled text. Based on the demonstrated value of both the beginning and end of a word for identification, it was hypothesized that holding the first and last letter constant should greatly improve both accuracy and speed of decoding as would be predicted by the spatial coding model of word recognition (Davis, 2010).

We also examined the role of expectation and context from the preceding words in the sentence. Although a scrambled word might be examined in isolation, the vast majority of our daily word identification comes in the context of a word in a sentence. Previous research has shown the value of prior context for word identification (e.g., West & Stanovich, 1986; Wright & Garrett, 1984) because this information may help readers predict what word will come next. Given these findings, we explored whether this would be true not just for correctly presented words, but also for scrambled word identification. In Experiment 1, sentence context was examined by manipulating the order of the words in the sentence. Although the scrambled word always appeared at the end of a sentence, the words of the sentence itself were sometimes reordered. This manipulation would, therefore, inhibit the ability of the reader to take full advantage of the contextual information in the text for predicting the identity of the scrambled word. If participants wished to make use of the entire sentence, they would have to take the extra time to first unscramble the sentence itself (assuming they even recognized that it made a proper sentence). Given the prior demonstrated benefit of semantic and syntactic information for word processing (e.g., Miller et al., 1951; Wright & Garrett, 1984), we predicted that having the words of the sentence stem randomized should harm accuracy and speed of decoding for the unscrambling task.

There is some evidence from Schriefers, Friederici, and Rose (1998) that scrambled sentences can be used to predict the final words of a sentence. It was unlikely, however, that this would be the case in the present research because Schriefers and colleagues used only sentence stems that were three words long, and our sentences were generally longer. Other studies using more complex scrambling methods such as longer sentences (Simpson, Peterson, Casteel, & Burgess, 1989) and additional replacements (O’Seaghdha, 1989) have not found any priming benefits for scrambled sentences. Thus, we predicted that decoding of the scrambled word should be harder, and slower, in sentences for which the word order was jumbled.

In addition to a sentence providing context for an upcoming word, the sentence itself could predict that a specific word will be seen. In Experiment 2, the importance of the sentence was explored by manipulating the predictability of the final scrambled word. This level of predictability was previously normed by a separate set of individuals. Although our participants were only instructed to unscramble the final word and were never told to read the entire sentence, it was hypothesized that they should find it easier to unscramble the highly predictable than the unpredictable words (as in lexical decision studies such as Schwanenflugel & Shoben, 1985). We predicted that having a context in which the scrambled word met the built-up expectations of the reader should make the task of unscrambling the word easier because the reader may already have an idea of what to look for in that set of letters.

Overall, we predicted that target words using the fixed scramble type would be easier and faster to decode than those in the random scramble type (Experiments 1 and 2). Additionally, a more predictable target word should be easier and faster to decode. This predictability could stem from the orderliness of the sentence stem (Experiment 1) or the predictability of the target word itself (Experiment 2).

### Experiment 1

**Method**

**Participants.** Thirty-four college students (19 women) aged 18–22 at a small regional university participated. A power analysis using G*Power (Faul, Erdfelder, Buchner, & Lang, 2013) on a repeated-measures Analysis of Variance (ANOVA) with two independent variables determined that the required sample size is 34. All participants were native English speakers who either volunteered to participate without compensation or received course credit. One additional participant was removed from analyses because the criteria of being able to correctly complete half or more of the trials was not met.

**Materials.** On each trial, participants were presented with one of 80 sentences in which the final target word was scrambled. The sentences (including the final scrambled word) were between four and eleven words in length (M = 6.2 words). The 80 final target words were all nouns and had a frequency between 1,000 and 3,000 out of one
Across sentences, two variables were manipulated: the type of scramble used and the order of the preceding words in the sentence. For type of scramble, the final target word could be scrambled such that the first and last letters of the word were maintained (fixed scramble) or such that all letters were randomly scrambled (random scramble). For example, the target word emergency could be viewed as ergemency (fixed scramble) or germecyne (random scramble). No other criteria were used when creating the scrambled words, but we attempted, as much as possible, to limit how often letters that appeared in order in the word also appeared together in the scrambled versions. For sentence type, the preceding words in the sentence were either in correct syntactic order (fixed order) or were randomly reordered (random order). In the random order sentences, we limited the reordering such that the random order never had more than two words in a row that were correctly placed in relation to each other. The manipulation of these two variables led to four possible sentence conditions. Italicization is used to highlight the target word in the following examples, but they were not presented in italics to participants. For example, the sentence, “The cable went out because of the horrible storm,” was seen as one of the following: “The cable went out because of the horrible sortm” (fixed scramble–fixed order), “The cable went out because of the horrible tsrmo” (random scramble–fixed order), “Went horrible because out cable the of the sortm” (fixed scramble–random order), or “Went horrible because out cable the of the trsmo” (random scramble–random order).

Participants saw 20 sentences in each of these four conditions in a randomized order, and trial type was counterbalanced across participants. Each block of 20 trials had an equal number of sentences from each of the four conditions.

Procedure. Following approval by the DeSales University institutional review board, participants were recruited and tested individually. They were told that they would be viewing sentences presented on a computer screen one at a time using the program PsychoPy (Peirce, 2007). Their task on each trial was to unscramble the final word in the sentence as quickly and accurately as possible. After viewing each set of 20 sentences, participants could take as long a break as they desired. Upon decoding of the final target word in the sentence, participants used the keyboard to type the word in the correct spelling and hit the enter key to indicate completion. PsychoPy does not allow participants to fix typed errors, so participants were told to just keep going if they made a mistake or if they realized part way through that they were incorrectly unscrambling the target word. The timing of both the first keystroke of the typed word and of the enter key were recorded as measures of speed of unscrambling (timing began for each trial when the sentence first appeared). Although participants were encouraged to complete every trial, they were told that, if they were certain they would be unable to unscramble the word, then they could skip to the next sentence by just pressing the enter key. Only data from participants who accurately completed at least half of the unscramblings were included in the analyses.

Results
Scoring. Because participants were asked to type their answers, there were, unsurprisingly, some typographical errors. Any trial without a perfect match to the target word was inspected to determine whether this was an inability to complete the trial, an error in decoding, an error in typing, or a spelling error. For example, eight participants incorrectly spelled prescription as perscription, an unsurprising spelling error. Other obvious typographical errors included avariables (extraneous letter before the start of the word) and bariables (transposition by one position on the keyboard for the first letter) instead of variables. Any trial that was an obvious spelling or typing error was scored as correct unscramblings. These types of errors occurred on 274 of the 2,720 total trials and accounted for 13% of trials that were counted as correct. Clear mistakes such as panenim for makeup were counted as incorrect as were trials where the participant was unable to make a guess. Additionally, two participants discovered that silence could alternatively be unscrambled as license. These two trials made up less than 0.08% of the trials and were marked as accurate.

Overall accuracy. To determine whether sentence or scramble type influenced accuracy, a two-way repeated-measures ANOVA was conducted with sentence type (fixed order or random order) and scramble type (fixed scramble or random scramble) as factors and accuracy as the dependent variable (see Figure 1). This revealed significant main effects of both scramble type, $F(1, 33) = 141.04, p < .001, \eta^2 = .81$, and sentence type, $F(1, 33) = 11.108, p < .005, \eta^2 = .25$, on accuracy. Overall accuracy was highest for sentences presented in correct order and not scrambled, which occurred in the fixed order–fixed scramble condition. Accuracy was lowest for sentences presented in random order and scrambled, which occurred in the random order–random scramble condition. The interaction between these two variables was not significant, $F(1, 33) = 2.58, p = .12$, $\eta^2 = .07$. Planned comparisons for the scramble type variable showed that accuracy was significantly lower in the random scramble condition than in the fixed scramble condition $t(34) = 3.75, p < .001, \eta^2 = .49$.
accuracy for fixed scramble (91.8%) was greater than for random scramble (62.0%), and accuracy for fixed sentence order (80.2%) was greater than for random sentence order (73.5%). There was a significant interaction effect between scramble type and sentence type, \(F(1, 33) = 7.83, p < .01, \eta^2 = .19\). Post-hoc analyses using paired-samples \(t\) tests with Bonferroni corrections demonstrated that accuracy was higher for fixed scramble than for random scramble for both sentence types \((p < .001)\). Although accuracy was higher for fixed sentence order than for random sentence order when the target word had a random scramble \((p < .01)\), there was no difference when the target word had a fixed scramble \((p = .99)\).

**Speed of unscrambling.** Only trials where the word was correctly decoded were included in the analyses for speed of unscrambling. Using those trials, a two-way ANOVA examined the effect of scramble and sentence type on speed of unscrambling completion (see Figure 2). Speed of unscrambling was determined by measuring both the first letter typed \((FirstClick)\) and when the participant hit the return key to move on to the next trial \((MoveOn)\). Results for both measures did not differ qualitatively and thus only \(MoveOn\) will be reported. For \(MoveOn\), there was both a significant main effect of scramble type, \(F(1,33) = 75.23, p < .001, \eta^2 = .70\), and sentence order, \(F(1,33) = 51.89, p < .001, \eta^2 = .61\). Overall average completion speed for fixed scramble (7.8 seconds) was faster than for random scramble (14.0 seconds), and average completion speed for fixed sentence order (8.1 seconds) was faster than for random sentence order (11.1 seconds). There was also a significant interaction effect, \(F(1,33) = 6.74, p = .014, \eta^2 = .17\). Post-hoc analyses using paired-samples \(t\) tests with Bonferroni corrections demonstrated that participants were faster for fixed scramble than for random scramble for both sentence types \((p < .001)\). Although participants were faster for fixed sentence order than for random sentence order when the target word had a random scramble \((p < .01)\), there was no difference when the target word had a fixed scramble \((p = .28)\).

**Discussion**
The results of Experiment 1 added to a body of literature suggesting that not all manipulations of words are equally easy to decode. When the first and last letters of the scrambled word were held constant, participants were faster and more accurate at decoding the word than when the letters were completely scrambled. We found that the fixed scramble was easier to read regardless of the prior context of the sentence. This provides additional evidence for the claim that the middle of a word is less critical for identification than is the beginning (Rayner & Pollatsek, 1989) or the end of a word (Perea & Lupker, 2003). We also demonstrated that the context in which a scrambled word is presented was central to identification. Correctly ordering the preceding words of the sentence provided participants with extra contextual information.
that improved accuracy and speed of scrambled word decoding. However, participants only showed a benefit of the correctly ordered sentence when the word to decode had the random scramble. Of particular note is that participants were not required to read the entire sentence, they were merely instructed to decode the one scrambled word. Because the scrambled word was always the final word in the sentence, they did not ever need to pay attention to any other part of the text. Any use of the preceding sentence to aid with word identification was entirely driven by participants themselves.

The fact that the sentence order only influenced performance for the random scramble could suggest that, when the scramble condition was more difficult (as can be seen by the main effect of scramble type), participants were more likely to turn to the sentence itself for help in unscrambling the word. For the easier (i.e., fixed) scramble condition, the prior context was not important. This suggests that participants chose to take advantage of the context of the sentence when it was most beneficial for them to do so.

**Experiment 2**

In Experiment 1, we explored the value of sentence context for scrambled word identification by manipulating the order of the preceding words in the sentence. This meant that the final word either came at the end of a relevant sentence or after a seemingly random set of words. It could be argued that this is similar to having the target word in isolation as compared to having it in a sentence. Another way of exploring the role of context is to consider situations where the unscrambled word is, or is not, highly likely given the preceding context. In Experiment 2, we first used a norming procedure to identify a set of sentences that highly predicted a target word and another set of sentences that did not predict the target word. Then we presented those sentences to participants who completed a descrambling task. We predicted that highly predictable scrambled words (those that clearly match the previous context of the sentence) should be easier and faster to decode than unpredictable words.

**Method**

**Participants.** Fifty-seven adults were recruited using Amazon’s Mechanical Turk for the target word norming task. All “workers” self-reported as being both 18 or older and native English speakers. The length of time to complete the survey and hourly pay varied across participants depending on the version of the sentences they viewed and the speed at which they worked on the task. Data were collected over three postings, and the average time for completion of this task ranged from 11 min 54 s to 35 min 23 s (depending on the posting), and from this, participants were paid at an hourly rate between $3.60 and $7.56 based on their speed of task completion.

Thirty-six college students (29 women) aged 18–37 at a small regional university participated in the unscrambling task. All were native English speakers. Eight additional participants were removed from analyses because they did not follow instructions (1), did not meet the criteria of being able to correctly complete half or more of the trials (1), or because of computer error (6). Participants either volunteered to participate without compensation or received course credit.

**Materials.** Following exempt status determination from the DeSales University institutional review board, participants in the norming task were presented with sentences through Amazon’s Mechanical Turk. The questions were hosted on the online survey program Qualtrics (https://www.qualtrics.com/). Participants’ task was to rate the predictability of the final word of each sentence presented to them on 6-point Likert-type scale from 1 (very unexpected) to 6 (very expected). For each sentence, the final word was presented in all caps to ensure that participants were evaluating the predictability of the correct item. For example, we expected the sentence “Lavinia auctioned off the expensive JEWELRY” to be given a higher average rating than “Lavinia auctioned off the expensive SURFACE.” This goal of the norming procedure was to create the stimuli that would be used in Experiment 2.

An initial group of 23 workers viewed three versions each of 60 sentences for a total of 180 sentences. Each sentence stem was paired with a final word that was expected to have a high predictability rating; a final word that was expected to have a low predictability rating, and one that was expected to be neither highly predictable nor highly unpredictable (“average” ratings). Based on their average ratings for these sentences, a subset of the sentences was selected such that the predictable ending had an average rating of at least 4 out of 6, and the unpredictable ending had an average rating of less than 3 out of 6. Although we had initially hoped to have three levels of predictability, we were not able to create three distinct groups, and thus
the “average” ratings were not pursued further. Sentence stems that failed to find either a high or low predictability ending were given new final words in the second posting. This posting contained 61 sentences and was completed by 12 participants. The same procedure was followed to select high and low predictability endings. Because of the relatively small number of participants who completed the second posting, a final 22 participants viewed a set of 63 sentences, which included both the endings with a rating above 4 or below 3 from the second posting, and additional options for sentences that had not yet found an acceptable ending. These three postings resulted in a final set of 60 possible sentence stems with both a high and low predictability ending. As a result, the selection of an ending being either high or low predictability resulted from ratings from between 22 and 34 individuals.

After selection of the 60 sentence stems, it was discovered that a subset of the target words had multiple scrambles (such as tapas for pasta or below for elbow). For this reason, 48 of the sentence stems (without multiple unscramblings) were chosen to be analyzed as targets in the following experiment, and the 12 additional sentences were used as fillers. For these 48 target sentence stems, each had one high predictability and one low predictability ending. All sentences had between five and nine words, and the final word had between five and nine letters. Some examples for high/low predictability include, “Bryn drove too fast around the CURVE/GROUND,” “Her mother planned the extravagant WEDDING/ACCOUNT,” and Cassius hung the heavy PAINTING/NEWSPAPER.

The average frequency of the final words as determined by the Corpus of Contemporary American English (COCA; Davies, 2008) for the high predictability and low predictability endings was compared. A two-tailed t test found that frequency level for the high predictability words (average 39,329) and low predictability words (average 32,107) did not differ, t(94) = 0.82, p = .47. Importantly, however, the high predictability endings did have a significantly higher rating (average 4.93) than the low predictability endings (average 3.98), t(94) = 3.40, p < .0001, d = 0.95 one-tailed.

Procedure. The procedure for Experiment 2 was nearly identical to that in Experiment 1. On each trial, participants were presented with one version of each of the 48 previously normed sentences and 12 filler sentences.

For each of the 48 target sentences, either the high predictability or the low predictability ending was used, and as in Experiment 1, the final word could have a fixed or random scramble. For example, the sentence stem “The little girl thanked the kind” could have the final word be woman (high predictability) or turkey (low predictability). This sentence was seen as one of the following: “The little girl thanked the kind woman” (fixed scramble–high predict), “The little girl thanked the kind anomw” (random scramble–high predict), “The little girl thanked the kind tkurey” (fixed scramble–low predict), or “The little girl thanked the kind ndkytu” (random scramble–low predict). As in Experiment 1, participants were given a break after each set of 15 sentences, and their instructions were the same as before.

Results

Scoring. As in Experiment 1, answers that were clearly typos or spelling errors were scored as correct. Spelling or typing errors occurred on 121 of the 1,728 total trials and accounted for 10.7% of trials that were counted as correct.

Overall accuracy. To determine whether predictability or scramble type influenced accuracy, a two-way repeated-measures ANOVA was conducted with scramble type and predictability as factors, and accuracy as the dependent variable (see Figure 3). This revealed significant main effects of both scramble type, F(1, 35) = 159.42, p < .001, η² = .82, and predictability, F(1, 35) = 298.83, p < .001, η² = .90, on accuracy. As in Experiment 1, overall average accuracy for fixed scramble (80.9%) was greater than for random scramble (50%). Additionally, average accuracy for the high predictability words (80.0%) was greater than for low predictability words (50.9%). There was also a significant interaction effect, F(1, 35) = 10.97, p = .002, η² = .24. Post-hoc analyses using paired-samples t tests with Bonferroni corrections demonstrated that accuracy was higher for fixed scramble than for random scramble for both levels of predictability (p < .001). Accuracy for high predictability words was greater than for low predictability words (p < .001). Accuracy for low predictability words was greater than for high predictability words (p < .001). Accuracy for fixed scramble was greater than for random scramble (p < .001).

Although data from the 12 filler trials was not included in the following analyses because of the complication that some words had multiple unscramblings, we did examine these trials. The filler trials showed the same pattern of results as the 48 target sentences. It is unlikely, therefore, that participants were aware of the differences between the target and filler sentences.
low predictability words for both scramble types \((p < .001)\). Overall, accuracy was highest for fixed scramble with high predictability and lowest for random scramble low predictability.

**Speed of unscrambling.** Only trials where the word was correctly decoded were included in the analyses for speed of unscrambling. Using those trials, a two-way ANOVA examined the effect of scramble type and predictability on speed of unscrambling completion (see Figure 4). Results for the two measures of speed did not differ qualitatively, and thus only MoveOn (when participants indicated that they had completed typing the word) will be reported. For MoveOn, there was both a significant main effect of scramble type, \(F(1,35) = 44.40, p < .001, \eta^2 = .56\), and predictability, \(F(1,35) = 34.23, p < .001, \eta^2 = .49\). Once again, overall average completion speed for fixed scramble (8.3 seconds) was faster than for random scramble (19.7 seconds). Additionally, average completion speed for the high predictability words (9.4 seconds) was faster than for low predictability words (18.7 seconds). There was also a significant interaction effect, \(F(1,35) = 12.64, p < .005, \eta^2 = .27\). Post-hoc analyses using paired-samples \(t\) tests with Bonferroni corrections demonstrated that participants were faster for fixed scramble than for random scramble for high predictability words \((p < .05)\) and low predictability words \((p < .001)\). Although participants were faster for high predictability words than for low predictability words when there was a random scramble \((p < .001)\), there was no difference when the target word had a fixed scramble \((p = .36)\).

**Discussion**

Once again, we found that participants were fastest and most accurate at unscrambling target words when the first and last letters were held constant. This was true regardless of the level of predictability of the final words. This served as additional support for our initial prediction that the beginning and end of scrambled words would be particularly important for scrambled word identification. Additionally, we found that participants were more likely to be able to decode the high predictability words than the low predictability words, regardless of the type of scramble. Scramble type and predictability interacted such that high predictability words with a fixed scramble were the easiest to read, and low predictability words with a random scramble were the most difficult to read. This greater facility for predictable words suggests that the previous words in each sentence built up an expectation about what that final word might be. As demonstrated by Van Berkum et al. (2005), it is possible that, by the end of a sentence, readers had focused in on a small set of possible final words that they were considering. When the scrambled words aligned well with the context and matched one of those possible words, this expectation might have made the words easier to identify because readers only needed to sample from that small lexical subset in order to complete the task. The predictability of a word has been found to influence response times...
in both lexical decision (Wright & Garret, 1984) and word naming tasks (West & Stanovich, 1986). However, our participants only showed a reduced response time for highly predictable words when the random scramble type was used. When the easier (i.e., fixed) scramble condition was used, the predictability of words did not significantly influence speed of response. Again, this shows that participants were able to take advantage of the contextual information in each sentence rather than just focusing on the target word, although they might have only chosen to do so when faced with a more challenging scramble condition.

**General Discussion**

Prior work has demonstrated that there is a time cost to reading words with reordered letters (Rayner et al., 2006), but most studies of scrambled word recognition have focused on the value of that word for priming tasks (e.g., Perea & Lupker, 2003) rather than reading in context. Our goal was to more closely examine factors that influence people’s ability to decode scrambled words. We found that both the method of word scrambling and the prior context of the sentence significantly impacted accuracy and speed of scrambled word decoding, but not to the same degree.

Across Experiments 1 and 2, we manipulated the type of scramble used. It has previously been demonstrated that the beginning and the end of a word are particularly important for word identification. When letters are transposed or substituted, alterations that occur at the beginning of a word lead to slower overall reading times (Rayner & Kaiser, 1975; Rayner et al., 2006), and transpositions at the end of a word inhibit priming effects (Perea & Lupker, 2003). In line with the literature, participants were more likely to be able to accurately unscramble the final word of the sentence—and did so more quickly—when the first and last letters were in the correct position than when they were not. This was true regardless of the sentence level manipulations used. As previously demonstrated, these results indicate that the first and last letters of a word are important not only for letter transpositions but also for complete scramblings. We also provide a contrast to Rawlinson’s (1976) finding that scrambled text does not negatively impact comprehension. Although we did not directly measure comprehension, we did find that the way in which a word is scrambled influences not only speed of decoding but also whether a word is even identifiable at all. We can reasonably assume that when a word could not be recognized, the broader comprehension of the sentence did, in fact, suffer. These differences in results may have stemmed from the stricter scrambling method used in the present studies than in Rawlinson’s study. Perhaps the fact that Rawlinson held the first two and last two letters of the word constant was enough information to allow the reader to easily interpret the word, thus not impairing comprehension. As speed for reading the target word was not measured in that study, however, it is unclear whether that scrambling approach harmed reading time even if it did not harm comprehension. These results generally demonstrate that not all word scramble manipulations are equally problematic.

Our finding that most scrambled words can be identified would support any word recognition model that allows for some letter position flexibility (such as the spatial coding or SERIOL model). However, the fact that the fixed scrambling method was less disruptive overall to reading provides further evidence in support of the predictions of word recognition models, such as the spatial coding model (Davis, 2010), that give extra weight to the external letters of a word for the purpose of identification. This distinction should be considered in future modifications to word recognition models. Our results suggest that these positions in the word provide an important cue for word identification, possibly by narrowing the scope of possible words. By providing the first and last letters, we significantly decreased the set of lexical items from which the scrambled word could be found. This, of course, only helped if participants took advantage of this extra information.

The second factor that we examined was the role of the context in which the scrambled words were presented. In Experiment 1, the scrambled words were always found at the end of the sentence, but the usefulness of previous words was sometimes limited by having them in a random ordering. In Experiment 2, the predictability of the final word was manipulated. Sentences that are correctly ordered have been found to be easier to process than those with a seemingly random set of words (Miller & Isard, 1963) or even those that are acceptable but do not follow canonical word order (Tanaka et al., 2007). The assumption is that prior words in a sentence provide a context that then leads to easier recognition of individual words. Given that recognition of the final word of a sentence is faster and more accurate when that lexical item is expected (West & Stanovich,
1986; Wright & Garret, 1984), we predicted that both the correctly ordered sentence condition (Experiment 1) and highly predictable final word condition (Experiment 2) would lead to fast and accurate unscrambling. Although this prediction was generally confirmed, sentence context did interact with scramble type. In Experiment 1, we found that having a correct sentence order only improved accuracy and speed of unscrambling for the random scramble trials. In Experiment 2, having the target words be high predictability always improved accuracy, but it only improved reaction time for the random scramble trials. Across both experiments, when the fixed scramble type (which had an overall higher accuracy rate) was used, contextual information did not influence response times. It is possible that, when given a more difficult unscrambling (in this case the random scramble), readers may need to make use of any available predictive information in the sentence stem to help them complete the task. If the sentence then provides no useful context, readers need to rely on just their unscrambling ability (such as it might be for a single word with no context) or take extra time to unscramble the sentence stem. Help from the sentence context might not be as necessary for the easier scramble type. Although these results overall support previous literature showing that predictive context may be used to help identify an upcoming word, we show here that context is not equally effective across all sentences, but that it is most beneficial in particularly difficult decoding situations. In the present research, when given altered text, readers appeared to focus first on the target word and then only looked further, considering context, when necessary.

Although the discussion of word recognition models thus far has only focused on individual words, any theory that attempts to explain word recognition in the larger context of a sentence will need to consider the fact that information at both the individual word and sentence level matter for identification but perhaps not, as we demonstrated here, to the same degree. The complexity of the scramble method for a word may determine the degree to which context is used. It is possible that this same effect may occur for other types of altered, or otherwise difficult to read, words. Word recognition models that go beyond the individual word to consider the phrases or sentence level should consider the relative importance of these cues. In addition to informing models of word recognition, a deeper understanding of the relative importance of specific letter positions and context cues on people’s ability to interpret words could be useful in a more practical setting. For example, this knowledge might be beneficial for better understanding the broader reading process, the reading difficulties of young readers, or even in explaining effects of developmental or acquired dyslexia. For example, one rare form of acquired dyslexia causes individuals to have difficulties with letter position encoding. As a result, they may flip the location of letters within a word, thus reading forth as froth. Interestingly, these migrations are much less common for the first and last letters of a word than for the internal letters (Friedmann & Gvion, 2001). Our findings add to an understanding of how the reader responds to internal as compared to external alterations in letter position. This knowledge may add in the creation of word recognition models that can more accurately predict this form of letter position dyslexia.

Limitations and Future Directions
Possible limitations with the design of the present studies should be taken into account when considering the implications of this work. One of the downsides of the program we used to present the stimuli is that participants were not able to see what they were typing, nor were they able to fix typing errors. As a result, there were some situations where the accuracy of the unscrambling was not entirely obvious. For example, we had to determine whether vessel was either (a) a misspelling of vessel, (b) an unintended translation of the last two letters during typing, or (c) the result of a participant not being able to unscramble the word and randomly typing letters (and getting very close by chance). Across both experiments, a total of 395 trials had errors that were determined to be typing or spelling errors. These were distributed across participants with only one participant making no such mistakes. Of these judgments, the vast majority (89.1%) were cases where the participant clearly knew the correct word but made errors. For example, the participant might have started with an error but ended correctly, incorrectly pluralized, had an additional extraneous letter, or used a common misspelling. There were only 43 trials total (1.6% of all trials scored as accurate across both experiments) that were less clear and could be up to interpretation. Because of the rarity of these cases, any mistakes on our part when classifying the typos were unlikely to have any significant effect on our analysis. However, it would be preferable to use a data collection
method where participants could fix errors, and thus fewer guesses would have to be made. For this reason, future studies may wish to use more flexible experiment building software packages such as PsyToolkit (Stoet, 2017).

Given the finding that overall reading speed may moderate how word alterations influence priming tasks (Duñabeitia et al., 2014), it would be interesting to know whether this is also true for unscrambling tasks. One limitation of the present study is that, although we only included native English speakers in our tasks, we did not have any independent measures of reading ability. This could be measured through simple reading time (Duñabeitia et al., 2014) or by examining reading comprehension. Future studies may wish to examine whether the benefits of a fixed scramble condition are equally large for more or less proficient readers.

One problem that we encountered was that some of our target words had more than one possible unscrambling. For this reason, we were not able to analyze all the possible trials in Experiment 2. This limitation, however, could lead to an interesting line of enquiry. We demonstrated in the current work that the way a word is scrambled and the context in which it is found both impact word identification. Although we found that scramble type had a larger effect than sentence context overall on performance, it is not entirely clear how these factors play their role. One possibility would be to identify words with more than one possible unscrambling. If the target word was in the fixed scramble position for one unscrambling, but the sentence structure predicted the other unscrambling, what would our participants respond? This manipulation would allow an additional way for us to directly compare the importance of these cues.

In Experiment 2, we examined the effect of unpredictability on the final word unscrambling. Although the set of words used in both the high and low predictability conditions did not differ overall on word length or frequency, each list had a different set of words. In an ideal situation, the same scrambled word would be used with two separate sentence frames so that each target word could be, across participants, seen as either high or low predictability endings. In the current work, we compared sentence endings that were given either very high or very low predictability ratings and found, as expected, that the more predictable endings were easier to unscramble. It would be informative, however, to know whether this is an all or nothing effect (i.e., predictable or not) or whether it is a graded effect. Perhaps there is a threshold for how likely the final word is before we see any benefit for accuracy of identification. Future studies that compare words across a wider range of predictability (perhaps at three levels) would help to explore this question.

Although we demonstrated that the first and last letter of a word are differentially important for word identification, it is possible, given our manipulation, that there is a second explanation for these results. Because we compared target words with the first and last letters maintained versus those that were completely scrambled, these two conditions were not exact comparisons as far as the number of letters to be rearranged. For example, in a six-letter word, you would only need to reorder the middle four letters instead of potentially all six (although the first and last letters in the random condition could not be in the accurate position, it was possible for one or more of the other letters to, by chance, be in the correct location). This could mean that participants performed better on the fixed trials because they are easier due to the number of letters to unscramble. The fact that only half of the trials had target words in this condition means that it is unlikely that participants were expecting and, thus, taking advantage of this possible benefit, but it should be considered. To confirm that it is the position of the first and last letters in particular that are important, additional studies should compare performance on those words to words where the middle two letters are fixed. This would allow for a more matched comparison set. As a related question, are both the first and last letter positions necessary for this effect? Would just holding the first letter constant also improve word identification?

There are many other open questions regarding word identification. We always put our scrambled word at the end of the sentence so as to potentially build up context and expectations. Our instructions to participants, however, did not tell them to read the whole sentence. If the scrambled word came first, would they still be likely to use the other information available? Another issue concerns the words that we asked participants to read. One commonality across much of the literature exploring word recognition is a focus on nouns. How does people’s ability to decode scrambled nouns compare to performance for other parts of speech? Would people see the same effects of context and scramble type in that case?

In summary, we examined two factors that...
influence people’s ability to decode scrambled words. We found that holding the first and last letters constant made the scrambled words easier to identify. This adds to a body of literature suggesting that the first and last letter positions of words are particularly important for word identification. Although words where the first and last letters were not held constant were more difficult to unscramble overall, we found that context could influence performance on those trials. Decoding accuracy and speed improved when the sentence helped to predict the identity of the scrambled word. Having the prior words in the sentence in the correct order (versus randomly scrambled), or having the target word itself be a likely ending to the sentence, increased accuracy and speed of decoding.

References


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