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Detecting spelling errors in compound and pseudo-compound words

Jenna M. Chamberlain

Christina L. Gagné

Thomas L. Spalding

University of Alberta, Edmonton, Alberta, Canada

Address correspondence to:

Christina L. Gagné
University of Alberta
Department of Psychology
P-217 Biological Sciences Building
Edmonton Alberta Canada T6G 2E9

cgagne@ualberta.ca
Phone: (780) 492-0034
Fax: (780) 492-1768

Abstract

Three experiments using a spelling error detection task, in which participants were asked to determine whether words have a spelling error, investigated the extent to which morphemes and pseudo-morphemes affect word processing. We compared the processing of transparent compound words (e.g., *doorbell*), pseudo-compound words (e.g., *carpet*), and matched control words (e.g., *tomato*). In half of the compound and pseudo-compound words, spelling errors were created by transposing adjacent letters and, in half of the control words, errors were created by transposing letters at the same location as the matched compound or pseudo-compound words. The response time and number of correct responses were analyzed. We consistently found that correctly spelled compound words were more easily processed than matched control words, while pseudo-compound words showed a processing deficit, relative to their matched control words. When letter transpositions were introduced at the (pseudo)morpheme boundary, these effects attenuated. The results strongly suggest that morphological processing is attempted obligatorily when the orthography indicates that morphological structure is present. However, the outcomes of the morphological processing attempts are different for compounds and pseudo-compounds, as might be expected, given that only the compounds have a morphological structure that matches the structure suggested by the orthography. The findings reflect two effects: an orthographic effect that is facilitatory and not sensitive to morphological structure of the whole word, and a morphemic effect that is facilitatory for compounds but inhibitory for pseudo-compounds.

Keywords: spelling; compound words; morphology; pseudo-compounds; morphological decomposition; lexical access

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It seems, intuitively, that morphemes are recovered when they are productively used within a compound morphological structure (e.g., *snow* and *ball* for *snowball*) but not when they are only incidental and not involved in the morphological structure of a word (e.g., *hip* and *pie* in *hippie*). However, is this intuition correct? The aim of the current set of experiments is to investigate whether words are automatically segmented into morpho-orthographic units and, if so, whether the morphemic structure of the word influences the impact of the retrieved morphemes. In particular, we will examine whether the availability of morphemes differentially influences the processing of compounds and pseudo-compounds (i.e., words that do not have a compound structure but can be split into two free morphemes). To do so, we evaluate the impact of embedded morphemes on the recognition of words for which those morphemes are used productively or not (i.e., have a false morphemic structures) as measured by the ease with which people can decide whether the words contain spelling errors. In this paper, we begin by discussing the theoretical issues concerning morphological decomposition and automatic segmentation and overview previous findings on the impact of transposed letters before introducing a spelling error detection task as way of evaluating the impact of morpheme availability on word recognition.

Although there has been substantial evidence to suggest that morphological representations become available during the processing of morphologically complex words (e.g., Andrews & Davis, 1999; Beyersmann, Castles, & Coltheart, 2011; Gagné & Spalding, 2004, 2009; Gagné, Spalding, & Figeuredo, 2009; Ji, Gagné, & Spalding 2011; Libben, 1994; Sandra 1994; Taft & Forster, 1975), there is still debate about when decomposition happens as well as about the impact that the constituent representations have on word access. Some researchers argue that access to morphological representations happens after the meaning of the whole word is accessed (e.g., Giraudo & Grainger, 2001; Giraudo & Voga, 2016; Levelt, Roelofs, & Meyer, 1999). However, others have suggested that decomposition happens early in processing, before the meaning of the whole word has been obtained, based on orthographic or morpho-orthographic representations (e.g., Crepaldi, Rastle, Coltheart, & Nickels, 2010; Rastle, Davis, & New, 2004; Taft & Forster, 1975). Findings supporting this approach come from masked priming lexical decision experiments (e.g., Beyersmann, Ziegler, Castles, Colheart, Kezilas & Grainger, 2016; see also Longtin, Segui & Hallé 2003 for similar findings in French; Diependaele, Sandra & Grainger 2005 for Dutch; Kazanina, Dukov-Zheleva, Geber, Kharlamov & Tonciulescu 2008 in Russian) indicating that stem morphemes become available when a word contains a suffix, regardless of whether the word has a stem+affix morphological structure (e.g., *hunter*) or not (e.g., *corner*), but not when the word does not contain an affix (e.g., *cashew*). Primes with a true morphological structure (e.g., hunter-HUNT) or with a pseudo-morphological structure (e.g., corner-CORN) equally aided the processing of the target whereas non-suffixed control words (e.g., cashew-CASH) do not aid.

The bulk of research on morphological decomposition has focused on affixed and pseudo-affixed words and, thus, it is still an open question as to whether words that contain embedded free morphemes but no affixes (namely, compound and pseudo-compound words) also show similar effects. Although compounds (e.g. *necklace*) appear to be the equivalent of *hunter* and pseudo-compounds (e.g., *carpet*) appear to be the equivalent of *corner*, it does not directly follow that stems would be recovered in the absence of affixes or that the identification of these morphemes would be beneficial in all cases. Indeed, some research has suggested that affixes and stems differ in terms of their sensitivity to position (e.g., Crepaldi, Rastle, Davis, & Lupker, 2013). Moreover, the lack of facilitation from non-suffixed words (e.g., *cashew*) in previous research (e.g., Beyersmann, et al., 2016) suggest thats the presence of a free morpheme (e.g., *cash*) is not beneficial in the subsequent processing of that morpheme if the remaining part of the word (e.g., *ew*) is not a legal morpheme. However, some non-suffixed items in previous experiments (see, e.g., Beyersmann et al., 2016) did contain two legal morphemes (e.g., *ad+dress*, *beg+in*, *drag+on*, *car+rot*, *car+ton*) and, consequently, had a pseudo-compound structure, as did some of the pseudo-suffixed words (e.g., *leg+ion*; *lot+ion*, *miss+ion*, *port+ion*; *ion* can refer to a type of atom and is an unbound morpheme, as well as having a suffix meaning). Therefore, past research does not provide an unambiguous indication of whether words with a pseudo-compound structure (e.g., *carpet* and *carrot*) would benefit from the identification and access of embedded morphemes in the same way that words with a true multi-morphemic structure (e.g., *farmer* and *necklace*) do.

In terms of this issue, various theoretical approaches make different predictions concerning whether compound or pseudo-compound structures will be differentially influenced by the recovery of embedded morphemes. Some theoretical approaches suggest that there would be a benefit. For example, Grainger and Beyersmann (2017) suggest that the presence of a stem morpheme has different effects on the availability of the whole word depending on the morphemic status of the other morpheme. For example, they suggest that non-suffixed words such as *pigeon* do not facilitate the processing of an embedded stem (e.g., *pig*) because *pig* inhibits *pigeon* plus the attempt at "… full decomposition fails: *pig* + ?)" (Grainger &

Beyersmann 2017, p. 302). In contrast, for pseudo-suffixed words (e.g, *corner: corn* + *er*) the inhibition of *corner* by *corn* is offset by the presence of *er* which allows for full decomposition into a stem + affix pseudo-structure, such that *corner* facilitates the processing of *corn*. Thus, by this explanation, facilitation of the stem is seen for pseudo-affixed words but not for non-suffixed words, even when the non-suffixed word contains two morphemes. Note that in this example, *eon* is, like *pig,* a free morpheme and, thus, *pigeon,* although non-suffixed, has a pseudo-compound structure and could be decomposed into two free morphemes if segmentation into morphemes occurs in the absence of an affix. Extending this account to pseudo-compounds (e.g., *carpet*), one would predict that the presence of a stem and a stem (e.g. *carpet*) will have a different consequence than the presence of a stem in a non-suffixed word (e.g., *cashew*). That is, if the recovery of a stem occurs only for words that contain an affix (as suggested by Grainger and Beyersmann's explanation of why *pigeon* does not facilitate *pig*), then pseudo-compounds (e.g., *carpet* and *pigeon*) should not show facilitation relative to an unrelated control word.

On the other hand, Grainger and Beyersmann (2017, p. 300) suggested that bi-morphemic nonwords (e.g., *dustworth*) take longer to process than nonwords consisting of a nonword and a word due to lexical activation from both embedded morphemes which suggests that stems can be recovered even when a word does not contain affixes. If this is the case, then pseudo-compounds should also show facilitation relative to an unrelated control word due to the principle of full decomposition and the two stems providing additional lexical activation, even though the item has a false bi-morphemic compound structure. Other models such as the one proposed by Crepaldi et al. (2010) also predict facilitation because they posit facilitatory links between units at the morpho-orthographic segmentation level (e.g., *corn*, *er*, *deal*) and representations in the orthographic lexicon (e.g., *corn*, *corner*, *deal*, *dealer*). Within this framework, one would expect pseudo-compounds to benefit from morpho-orthographic segmentation because the segments (e.g., *car* and *pet* in the case of *carpet* or *son* and *net* in the case of *sonnet*) would correspond to representations in the orthographic lexicon. Thus, based on these explanations that have been put forth based on pseudo-affixed words and bi-morphemic nonwords, one can predict either that embedded morphemes do not influence the processing of pseudo-compounds or that the influence would be beneficial.

In contrast, models that adopt a competitive selection mechanism (see Andrews & Davis, 1999, for a discussion) predict that activated representations of the whole word (e.g., *blackbird*) and constituents (e.g., *black* and *bird*) compete and could delay identification of the whole word, although there is some evidence that high-frequency constituents appear to benefit compound processing (Taft & Forster, 1976) at least in the case of semantically transparent compounds. Ji et al. (2011) have found that high frequency constituents aid the processing of transparent compounds (e.g., *snowball*) but slow the processing of opaque compounds (e.g., *hogwash*). Extending these findings to pseudo-compounds, one would predict that embedded morphemes would produce inhibition for pseudo-compounds but would yield facilitation for transparent compounds.

Another factor to consider in predicting whether the identification of morphemes would benefit or hinder the processing of pseudo-compounds concerns the possibility that the role of morphemes might not be restricted only to accessing a stored representation of the compound, but also that they are used to actively construct meaning (Gagné & Spalding, 2009; Taft, 2003). That is, rather than influencing processing primarily via conjunctive activation of the compound, constituents also influence processing due to their involvement in a constituent integration process during which the system uses available constituents to construct morphological structures and engages in an interpretive, semantic composition process. Consequently, the identification of morphemes would be beneficial for compounds due to their compatibility with the actual structure, but not beneficial for pseudo-compounds due to their incompatibility with the actual morphological structure (e.g., assigning *car* and *pet* to the two constituent positions in a compound structure conflicts with the actual, mono-morphemic, structure of *carpet*).

In sum, it is unclear whether legal stems in words without affixes are always identified regardless of the morphological structure of the whole word and, if so, whether this segmentation differentially influences the ease of processing compound and pseudo-compound words. In the current experiments, we examine the issues of automatic morphological segmentation and the consequences of a false morphological structure in the context of transposed letters. Examining whether letter transpositions affect word recognition provides information about the types of information people use during word processing. Early research by Bruner and O'Dowd (1958, see also Rayner, White, Johnson, & Liversedge, 2006) found that reading was most disrupted by switches at the beginning, next most disrupted at the end, and least disrupted by switches in the middle of the word. They concluded that the "edges" of a word appear to be more relevant than the middle of a word in terms of word recognition. However, these conclusions might not extend to compound words (i.e., words for which mid-word letter transpositions disrupt the morpheme boundary). Past work has shown that the ability of a nonword with transposed letters to activate its base word is reduced when the letter transposition occurs across a morpheme boundary. For example, Christianson, Johnson, and Rayner (2005, see also Duñabeitia, Perea, & Carreiras 2007 for a similar pattern for prefixed and suffixed words in Spanish and Basque) found that naming times for compound words (e.g., *sunshine*) were faster relative to a control condition (e.g., *sunsbine*) when the prime contained transposed letters within a morpheme (e.g., *sunhsine*) than when the prime contained transposed letters that crossed the morpheme boundary (e.g., *susnhine*). Both types of switches were in the middle of the entire word, and yet switches at the morpheme boundary more greatly disrupted the ability of the prime to facilitate processing of the target. This result suggests that morphologically complex words are decomposed early in processing and that the morphemes are involved in boosting activation to the whole word representation. It is worth noting that transpositions across the morpheme boundary do not entirely disrupt the recovery of morphemic representations because other studies have found evidence of facilitation from primes containing transpositions at the morpheme boundary (e.g., Perea & Carreiras, 2006; Rueckl & Rimzhim, 2011; see also Beyersmann, McCormick, & Rastle, 2013 for a discussion of data on this issue). Overall, changes at the morpheme boundary appear to be more disruptive than changes that occur within a morphological constituent which suggests that morpheme decomposition occurs early in word recognition.

Overview and Rationale of Current Experiments

The current studies investigate the effects of the presence of two adjacent free morphemes on the processing of compound and pseudo-compound words using a spelling error detection task and transposed letters at the (pseudo-) morphemic boundary. The letter transposition introduces a spelling error into the stimuli (e.g., *neclkace*) without changing the intended word and thus we take advantage of this aspect of the letter transposition manipulation by using a spelling error detection task to explore the role of morphemes in word recognition.

Across three experiments, we manipulate word type (compound, pseudo-compound, and control words) and presence of a spelling error in order to examine the role of embedded morphemes in the context of words for which the morphemes can be correctly assigned to a compound morphological structure and for words for which the compound structure is false. In Experiment 1, we examine whether it takes less time to indicate that a compound is correctly spelled relative to a control word, and, if so, whether a letter transposition at the morpheme boundary removes this advantage by making the morphemes more difficult to detect. In Experiment 2, we examine whether the presence of morphemes influences the processing of pseudo-compounds relative to a control word. In Experiment 3, compound and pseudo-compound words are examined in the same experiment. For all experiments, the control words had a letter transposition at the same letter location as their frequency- and length- matched compound/pseudo-compound word.

Although a spelling error detection task has not yet been used to examine the issue of morphological decomposition, it has been used to examine other aspects of lexical access. For example, a version of this task was used by MacKay (1972, see also MacKay, 1992, for a review) to examine the influence of phonology on lexical access. We adapted this task for exploring questions about the role of orthography and morphology. In our version of the task, participants indicated, by pressing one of two keyboard keys, whether the word was spelled correctly. The spelling error detection task involves a procedure similar to a lexical decision task, in that both require a yes/no judgment, but it has several advantages. One advantage is that additional items are not needed as fillers to balance the number of yes and no responses. The spelling error condition serves this purpose, while presenting the same intended words that the participant must access in order to identify that it is misspelled. Thus, the “no” responses are as informative as the “yes” responses in that both the correctly spelled and misspelling items provide useful information for evaluating the various hypotheses. Another advantage of a spelling error detection task is that the judgment is more naturalistic, and highly practiced than is a word/nonword judgment, particularly for university students. Consequently, decisions about spelling more directly tap into information about word form (e.g., orthography) and do not involve meta-judgments about word status, which could be based on meaning or other factors as well as form. Finally, by using letter transpositions at the morpheme boundary, we are able to examine the potential role of morphology without relying on priming. Rather than looking at the influence of the recent presentation *necklace* on *neck*, for example, or of *neclkace* on *neck* to determine whether *neck* becomes available during the processing of the compound *necklace*, we directly look at the processing of *necklace* or *neclkace*. That is, the spelling task allows us to directly examine the processing of compounds and pseudo-compounds in a context where the constituents have not been recently viewed, rather than examining the consequences of a recently presented word on processing.

Previous work on compound processing has found evidence of automatic morpheme activation (e.g., Fiorentino & Fund-Reznicek, 2009; Libben, Gibson, Yoon, & Sandra, 2003). The focus of the current project takes a somewhat different direction. Our aim is to examine the impact of embedded morphemes on the processing of words containing those items. There is some indication that activating morphemes is beneficial, in that compounds are processed more quickly than control words, which suggests that the presence of morphemes aids in the recovery of the compound (Fiorentino & Poeppel, 2007; Ji, Gagné & Spalding 2011). The current experiments expand on this past research by more directly manipulating the ease with which the embedded morphemes can be recovered by introducing a letter transposition at the morphemic boundary. This manipulation allows us to evaluate whether the advantage is likely to be due to access to morphemic information. In particular, if the compound processing advantage suggested by previous research exists, and is due to early access of the constituent morphemes, then there should be a clear processing advantage in the spelling error detection task when the compound is correctly spelled. However, disrupting the morpheme boundary should slow detection of the constituents and, thus, remove or attenuate the compound advantage.

Examining both words for which the embedded morphemes are productive (i.e., compounds) and for which the embedded morphemes are not productive (i.e., pseudo-compounds) allows us to explore various theoretical approaches concerning whether morphemes are automatically detected and if so whether the presence of these morphemes aid or hinder recognition of the whole word. If embedded morphemes are not recovered during the processing (i.e., if words are accessed as whole-word representations without decomposition) then compounds and pseudo-compounds should not differ from frequency and length matched control words, and the impact of letter transpositions should be equivalent for the experimental and control words. However, if all morpho-orthographic representations are recovered and have facilitatory connections to words containing those letter sequences (e.g., Crepaldi et al., 2010), then both compounds and pseudo-compounds would benefit from the recovery of morphemes. Similarly, letter transpositions which make it more difficult to identify the morphemes should decrease the extent to which the presence of the morphemes benefits word processing. Finally, if the recovery of morpho-orthographic representations triggers a composition process (Gagné &

Spalding, 2009) then compounds should show a processing advantage relative to control words because morphemic composition would yield a morphological structure that is compatible with the true structure, and also the morphemes would boost activation of the compound, whereas pseudo-compounds should not show this advantage because the computed compound structure (triggered by the presence of two free morphemes) would be incompatible with the actual morphemic structure of the pseudo-compound. Moreover, a letter transposition would make it more difficult to recover the morphemes which would increase the difficulty of constructing the compound structure. This increase in difficulty would attenuate the processing advantage for compound words, but would (relatively) benefit the processing of pseudo-compounds by reducing the interference from an incompatible morphemic structure.

Experiment 1

Past research has found that semantically transparent compounds were processed more quickly than were frequency-matched control words (e.g., Ji et al., 2011), suggesting that the constituents of the word facilitated access the compound. In addition, studies of typing have shown that the morphological structure of compound words lead to different processing than is seen in non-compound control words (Gagné & Spalding, 2014a, 2016); in particular, there is an elevation of typing times at the morpheme boundary for compound words which also suggests that constituent morphemes are involved in compound processing.

The aim of this experiment is to determine whether compound words show a processing advantage in a spelling error detection task, and, if so, whether this advantage is disrupted by a letter transposition at the morpheme boundary. Unlike previous work on compounds and transposed letters (e.g, Christianson et al., 2005) that uses the item with the transposed letter as a prime (e.g., *susnhine*) to see the impact that manipulation has on subsequently naming a compound versus a control word (e.g., *sunshine* vs. *sunsbine*), the current experiment takes a different approach in that it directly compares the compound and transposed letter item to their frequency- and letter-matched control words. Thus, in addition to determining whether compounds undergo early decomposition, we also examine the consequences of that decomposition in terms of the role that the morphemes play in word recognition (as measured by the ease with which people can decide whether the word is correctly spelled).

By examining whether a letter transposition at the boundary influences the compound processing advantage, we can more directly test the proposal that the compound advantage is due to morphemes becoming available early in word processing. In particular, manipulations (such as transposing the letters at the morpheme boundary) that make it more difficult to recover the morphemes should attenuate the processing advantage for compound words. It seems more likely that the processing advantage would be attenuated rather than eliminated because previous research using masked priming has found that disruptions at the morpheme boundary do not entirely disrupt the recovery of morpho-orthographic units (e.g., Christenson et al. 2005; Perera & Carreiras 2006; Rueckl & Rimzhim 2011).

Method

Materials. The experimental materials included 80 control and 80 fully transparent compound words (see Appendix A). Each compound word was matched with a control word in terms of SUBLEX-US log frequency (Brysbaert & New, 2009) and letter length (within 1 letter). The control words did not have a compound structure. To ensure that there were no unintended repetition priming effects, all morphemes were unique and no words were repeated. A spelling error was created by transposing two adjacent letters within the word. For the compound words, the transposition was at the morpheme boundary such that the last letter of the first constituent and the first letter of the second constituent were switched (e.g., *doorbell* became *doobrell*). For the control words, the letters were transposed at a location within the word that matched the location of the switch in the matched compound word. For example, the fourth and fifth letters of *particle* would be transposed to make *paritcle*, so that it matched the position of the switch in *doobrell*. Thus, the compound and control pairs were matched in terms of whole-word frequency, length, and position of the relevant bigrams.

The frequency and transition probabilities of the relevant bigrams (e.g., the *rb* in *doorbell* and *br* in *doobrell*) were free to vary and their influence was controlled statistically in the analysis. Bigram frequencies were obtained from Jones and Mewhort (2004). Transition probabilities were calculated based on the SUBLEX-US corpus and was defined as the total count of the number of words in which both letters (bigrams) occur together, divided by the total number of times the first letter occurs in the word. See Table 1 for the descriptive statistics for the stimulus variables.

The stimulus lists were counterbalanced across two lists such that across the two lists every word was seen with and without the spelling error. Each list contained only one version of each stimulus (e.g., a given participant would see either *doorbell* or *doobrell*). Thus, each list had 80 compound words, of which 40 were correctly spelled and 40 had errors, and 80 control words, of which 40 were correctly spelled and 40 had errors. An additional 80 compound words and 80 control words were selected to be the fillers so that the spelling errors did not always occur in the middle of the word. Half of the fillers were spelled correctly and the others were spelled incorrectly. The spelling errors were created by switching adjacent letters at random locations within the word. Random switches within the fillers distributed the spelling errors evenly across letter positions in order to prevent participants from only looking at the middle of the words and skewing their reaction time over the course of the experiment. The final filler list had 80 compound words, of which 40 were correctly spelled and 40 had randomly placed errors, and 80 control words, of which 40 were correctly spelled and 40 had randomly placed errors. Each person completed 320 trials and the order of presentation was randomized for each participant.

—- INSERT TABLE 1 ABOUT HERE —

Procedure. Each trial began with the word "Ready?" and participants pressed the spacebar to initiate the trial. Next, the stimulus appeared and remained on the screen until the participant responded. Participants responded with key 'J' if the word was spelled correctly and key 'F' if the word was spelled incorrectly.

Participants. Forty first-year psychology students at the University of Alberta participated for partial course credit. One subject was removed from the analysis due to high variability and long response times. All participants in the current experiment and in Experiments 2 and 3 were native speakers of English.

Results and Discussion

The data were analyzed using linear mixed effects (LME) regression models (Pinheiro & Bates, 2000; Rabe-Hesketh & Skrondal, 2012) in in Stata 15 (Statacorp, 2017) with the *mixed* function for the response time data and the *meqrlogit* for the binary (correct vs. incorrect) accuracy data. Participants and item were entered as crossed random factors, and Word-Type (compound vs. control) and Spelling (no error vs. spelling error) were entered as fixed factors.

To statistically control for the potential influence of bigram frequency and transition probability, these two variables also were included in the model.

Inverse response time (i.e., -1000/RT) was used for the reaction time analysis because the Q-Q plots revealed that the inverse transformation was better at correcting for skewness in the residuals than was the log transformation. Only trials with the correct response were included in the response time analysis and responses less than 350 (n = 4) were removed as outliers. One item in the control condition was removed because it had a pseudo-compound structure. The descriptive statistics are shown in Table 2.

—- INSERT TABLE 2 ABOUT HERE —

It is important to note that the results of all experiments, as analyzed, involve a comparison across different responses (i.e., for each initial analysis, we consider the spelling factor in interaction with the other manipulated factors before reporting the simple effects for the correctly spelled and for the misspelled conditions). This allows us to investigate the extent to which introducing a letter transposition spelling error changes the effects of the other manipulated factors on processing speed and accuracy. In lexical decision tasks, of course, researchers typically do not compare the response times to word and non-word responses because, by hypothesis, the word and non-word responses must involve very different processes. In particular, the idea is that the "word" response occurs when the incoming letter string accesses the word, but the "non-word" response can only occur when the person reaches some separate criterion that the letter string has mismatched all the words in the lexicon (because the question is not whether it matches a particular word, but whether it is a word at all). Thus, response time compared across these different responses in a lexical decision task is not easy to interpret. The spelling error detection task, on the other hand, does not have this kind of closed process versus open process associated with the two outcomes. In particular, previous research (e.g., Perea & Carreiras, 2006; Rueckl & Rimzhim, 2011) shows clearly that having transposed letters does not stop the participant from accessing the intended word. Thus, the “correctly spelled” response occurs when the spelling of the letter string matches the stored orthography of the intended word, and the “incorrectly spelled” response occurs when the letter string mismatches that stored orthography. Thus, the two responses in the current task do not correspond to large process differences in the way that they do in lexical decision. However, it is still the case that the differing responses might have other effects, so in each analysis we will consider the simple effects separately for the correctly spelled and incorrectly spelled stimuli. The simple effects most directly test the predictions of interest and will be our primary focus.

The response time analysis showed an interaction between Word-type and Spelling, $X^2(1) = 24.23$, $p < .0001$. When the words were spelled correctly, responses to the compounds were faster than were responses to the control words, $X^2(1) = 24.09$, $p < .0001$. This is consistent with past research showing that compound words are processed faster than non-compound control words of similar length and frequency (e.g., Ji, Gagné, & Spalding 2011). However, this advantage for compound words disappeared when the words contained a spelling error (i.e., when the morpheme boundary is disrupted), $X^2(1) < 1$. In terms of the control variables, response time increased as bigram frequency increased, $z = 2.63$, $p = .008$, but was unaffected by transition probability, $z = -0.14$, $p = .88$.

The accuracy analysis did not show an interaction between Word-type and Spelling, $X^2(1) < 1$, $p =.37$. Compound words were responded to more accurately than the control words, whether correctly spelled, $X^2(1) = 9.66$, $p < .002$, or incorrectly spelled, $X^2(1) = 8.33$, $p =.004$. In terms of the control variables, neither bigram frequency, $z < 1$, nor transition probability , $z < 1$, influenced accuracy.

In sum, the results suggest that it is easier to process compound words compared to the matched control words, and that this advantage is somewhat attenuated when there is a letter transposition at the morpheme boundary. Recall that compounds and their control were matched pairwise in terms of word frequency, and consequently, the observed processing differences can not be due to compounds being more familiar. Thus, it appears that access to the constituents aids access to the compound and this leads to a processing benefit. Disruptions at the morpheme boundary interfere with morphemic processing and limits the ability of the constituent representations to aid access of the compound. Finally, the results clearly show that the spelling error detection task is highly sensitive to the morphological structure of the word, and hence is a good task for investigating the role of morphology in processing.

Experiment 2

We suggest that the compound advantage observed in Experiment 1 is a consequence of morphological decomposition and the involvement of morphological constituents during the recognition of the compound. To further explore this possibility and to gain insight into the processing of items that contain embedded morphemes but do not have a compound structure, we investigated the the processing of pseudo-compounds. Pseudo-compounds such as *carpet* have the appearance of compound words (i.e., orthographically, it looks like a compound of *car* and *pet*), but in fact do not have a compound morphemic structure.

As discussed in the Introduction, the theoretical questions of whether the morphemes within a pseudo-compound (e.g, *carpet* and *lotion*) are automatically detected, and if so whether the presence of these morpho-orthographic representations help or hinder recognition of the pseudo-compound has not yet been fully explored. The prior literature suggests three general possibilities. First, if embedded morphemes are not recovered during the processing (i.e., if words are accessed as whole-word representations without decomposition) then the presence of embedded morphemes is irrelevant and pseudo-compounds should not differ in ease of processing from length- and frequency-matched control words. Also, the impact of a letter transposition should be equivalent for pseudo-compound words and their matched controls (e.g., each would be disadvantaged to the same degree). Second, if all morpho-orthographic representations are recovered and have facilitatory connections to works containing those letter sequences regardless of a word's true morphological structure (e.g., *hunt* is connected to *hunter* and *hunt* and *corn* is connected to *corner* and *corn)*, then the recovery of the pseudo-morphemes would aid participants' ability to determine whether the word was correctly spelled for the same reason that presenting as pseudo-affixed word such as *corner* speeds responses to the target *corn.* Similarly, letter transpositions which make it more difficult to identify the morphemes should decrease the extent to which the presence of the morphemes benefits word processing by slowing the access of the morpheme representations. Finally, if morpho-orthographic representations are recovered and used to construct a morphological structure then pseudo-compounds would be more difficult to process relative to length- and frequency-matched control words because the constructed morphological structure is incompatible with the actual structure of the word. That is, unlike compounds, pseudo-compounds would not benefit from the recovery of embedded morphemes.

Method

Materials. The experimental items consisted of 80 control words and 80 pseudo-compound words (see Appendix B). The pseudo-compound words could be parsed into two free morphemes but, unlike compound words, these morphemes do not function as such in the pseudo-compound (e.g., *lotion* contains *lot* + *ion,* but is mono-morphemic). Each pseudo-compound word was matched with a control word in terms of SUBLEX log frequency and letter length (within 1 letter). To create a spelling error in the pseudo-compound words, the adjacent letters at the embedded-morpheme boundary were switched (e.g., *carpet* becomes *capret*). In the control words, the letters were switched at the same location within the word as in their matched pseudo-compound words. Thus, the pseudo-compounds and their control word were matched in terms of word frequency, length, and position of the transposed letters. Bigram frequency and transition probability of the relevant bigrams were also obtained for inclusion in the analysis so that we could statistically control for their effects. See Table 3 for the descriptive statistics for the stimulus variables.

—- INSERT TABLE 3 ABOUT HERE —

The stimuli were counterbalanced so that each list included only one version (i.e., correctly spelled or misspelled) of each word. In total, each list had 80 control words, 40 correctly spelled and 40 with an error, and 80 pseudo-compound words, 40 correctly spelled and 40 with an error. In addition to the experimental stimuli, each participant saw a set of 80 control words and 80 pseudo-compound words as fillers. For half of the filler words, a spelling error was created in a random location, using the same steps as in Experiment 1, to distribute the spelling errors evenly throughout the word. All the other words were spelled correctly. The filler list had 80 pseudo-compound words, of which 40 were correctly spelled and 40 had an error, and 80 control words, of which 40 were correctly spelled and 40 had an error.

Procedure. The procedure was identical to Experiment 1.

Participants. Fifty first-year psychology students at the University of Alberta participated for partial course credit.

Results and Discussion

The data were analyzed using separate linear mixed effects regression models for the response time and accuracy data (see Experiment 1 for details). Inverse response time (i.e., -1000/RT) was used for the reaction time analysis to correct for skewness in the residuals. Only trials with the correct response were included in the RT analysis and responses less than 150 (n = 4) were removed as outliers. The descriptive statistics are shown in Table 4.

—- INSERT TABLE 4 ABOUT HERE —

In the response time analysis, there was no interaction between Word-type and Spelling, $X^2(1) = 2.00$, $p = .16$. Response times to pseudo-compounds did not differ from those to the frequency and length matched control words when the stimulus was correctly spelled, $X^2(1) = 1.37$, $p = .24$, but responses to the pseudo-compounds were slower than to the matched controls when a letter transposition was inserted at the pseudo-morpheme boundary, $X^2(1) = 6.40$, $p < .02$. In terms of the control variables, neither bigram frequency, z = 1.11, $p = .27$, nor transition probability, z = -1.55, $p = .12$, influenced response times.

In the accuracy analysis, there was no interaction between word type and error rate, $X^2(1) =1.03$, $p = .31$. Neither bigram frequency, $z = -.64$, $p = .52$, nor transition probability, $z = 1.25$, $p = .21$, influenced accuracy. Accuracy was lower for pseudo-compounds than for the control words when correctly spelled, $X^2(1) = 5.60$, $p < .02$, but not when incorrectly spelled, $X^2(1) = 1.99$, $p = .16$.

To determine whether pronunciation match or mismatch between the pseudo-morpheme and the pseudo-compound influenced spelling detection, we conducted another analysis using the correctly spelled pseudo-compounds in which we included whether the pronunciation of the first pseudo-morpheme (e.g., *son*) was maintained in the pseudo-compound (e.g., *sonnet*), along with the bigram frequency and transition probability control variables. Neither control variable affected either response time or accuracy. Response times for the correctly spelled pseudo-compounds were influenced by whether the pronunciation of the pseudo-morphemes matched the pronunciation of the pseudo-compound, $X^2(1) = 7.29$, $p = .007$, in that it took less time to indicate that the pseudo-compound was correctly spelled when the pseudo-morpheme's pronunciation was retained in the whole word than when the pseudo-morpheme's pronunciation differed from the related part of the whole word. Pronunciation match marginally predict accuracy , $X^2(1) = 3.17$, $p = .08$; when the pronunciation matches, performance is more accurate than when the pronunciation mismatches. These results suggest that the first constituent was being extracted during the processing of the pseudo-compound, because otherwise pronunciation of that pseudo-constituent should have no influence on the processing of the pseudo-compound. That is, the pronunciation of *son* could only be relevant if it was being accessed during the processing of *sonnet*.

In sum, the data indicate that the system attempts to recover morphemes, even if they do not play a morphological role in the target word, but unlike compounds and pseudo-derived words (such as *corner*) the presence of these morphemes do not benefit the processing of pseudo-compounds. The presence of embedded morphemes led to participants taking more time to indicate that a pseudo-compound was misspelled relative to its matched control, and to being less accurate in correctly indicating that a pseudo-compound was correctly spelled. Importantly, the pattern of data observed in the current experiment for pseudo-compounds is opposite to what was observed in Experiment 1 for compounds which indicates that the impact of the embedded morphemes is influenced by the true morphemic structure of the word.

Experiment 3

Experiments 1 and 2 revealed that the ease of processing pseudo-compounds and compounds differed from the control words, and that pseudo-compounds and compounds differed in terms of the direction of this difference in that compounds were easier to process than the length- and frequency-matched control words, whereas pseudo-compounds were more difficult to process than their control words. These effects were attenuated when a letter transposition is introduced into the word at the (pseudo)morphemic boundary, in response time for compounds, and in accuracy rate for the pseudo-compounds. In this experiment, we present all three types of words: compound words, pseudo-compound words, and their matched control words, and attempt to replicate the compound advantage and pseudo-compound disadvantage within the same set of participants and to test whether the different patterns of results for pseudo-compounds and compounds observed in the previous experiments were due to participant differences rather than due to word-type (i.e., compound vs. pseudo-compound) differences.

Method

Materials. We created the stimulus list by combining the word lists from Experiment 1 and 2 (see Appendix C). Two repeated words (both were the control items) in the experimental list were replaced with new words with the same length and frequency as the original words. Thus, the experimental items consisted of 80 fully transparent compound words (40 spelled correctly and 40 misspelled), 80 pseudo-compound words (40 spelled correctly and 40 misspelled), and 160 control words (80 spelled correctly and 80 misspelled). The filler items were created by combining the filler items from Experiment 1 and 2 and replacing any repeated items with new words. The filler items mimicked the structure of the experimental set except that for the misspelled items the adjacent letters were switched at random positions within the words to create the spelling errors. The filler items consisted of 80 compound words (40 spelled correctly and 40 misspelled), 80 pseudo-compound words (40 spelled correctly and 40 misspelled), and 160 control words (80 spelled correctly and 80 misspelled).

Procedure. The procedure was identical to Experiment 1.

Participants. Forty first year psychology students at the University of Alberta participated for partial course credit.

Results and Discussion

Separate linear mixed effects regression models were fit for the response time and accuracy data (see Experiment 1 for details). The predictor variables included three experimental variables of interest — Set (compound set vs. pseudo-compound set), isControl (compound/ pseudo-compound vs. matched control words) and Spelling (correctly spelled vs. misspelled) — as well as two control variables — bigram frequency and transition probability. Inverse response time (i.e., -1000/RT) was used to correct for skewness in the residuals. Only trials with the correct response were included in the response time analysis and responses less than 200 ms or greater than 10 seconds (n = 3) were removed as outliers. One item in the control condition was removed because it had a pseudo-compound structure. The descriptive statistics are shown in Table 5.

—- INSERT TABLE 5 ABOUT HERE —

In the response time analysis, neither bigram frequency, $z = 1.68$, $p = .09$, nor transition probability, $z < 1$ influenced response times. In terms of the experimental variables, the three-way interaction between Set, isControl and Spelling was not significant, $X^2(1) < 1$. The Set by isControl interaction was significant both when the items are spelled correctly, $X^2(1) = 9.87$, $p = .002$, and when spelled incorrectly, $X^2(1) = 5.43$, $p = .02$. Compounds were processed more quickly than their matched controls when spelled correctly, $X^2(1) = 7.29$, $p = .007$, but not when spelled incorrectly, $X^2(1) < 1$. In contrast, pseudo-compounds showed a processing disadvantage which was most readily observed in the misspelled condition: pseudo-compounds were processed marginally more slowly than their controls when spelled correctly, $X^2(1) = 2.78$, $p < .10$, and more slowly than their controls when spelled incorrectly, $X^2(1) = 10.3$, $p < .002$. In sum, compounds benefited from the presence of embedded morphemes, whereas pseudo-compounds were slowed by the presence of embedded morphemes.

In the accuracy analysis, there was a three-way interaction for the experimental variables, $X^2(1) = 19.98$, $p < .00001$, in that there was a Set by isControl interaction when the stimuli were spelled correctly, $X^2(1) = 23.37$, $p < .0001$, but not when the stimuli were spelled incorrectly, $X^2(1) < 1$. The compound items were more accurate than their matched control items when spelled correctly, $X^2(1) = 12.02$, $p = .0005$, but not when spelled incorrectly, $X^2(1) < 1$. The pseudo-compound items are less accurate than their matched controls when spelled correctly, $X^2(1) = 10.86$, $p = .001$, but not when spelled incorrectly, $X^2(1) < 1$. In terms of the control variables, bigram frequency, $z = -2.40$, $p = .02$, but not transition probability, $z < 1$ influenced accuracy; higher bigram frequency at the morpheme boundary was associated with lower accuracy. To summarize, in terms of the participants' ability to correctly indicate whether the word was spelled correctly, a letter transposition at the morpheme boundary disrupted the processing advantage for compounds and the processing disadvantage for the pseudo-compounds.

Considering both the reaction time and accuracy analyses, we see a clear replication of the patterns of Experiments 1 and 2 in that pseudo-compounds and compounds produced opposite effects: compounds produced a processing advantage relative to their matched controls, whereas pseudo-compounds produced a processing disadvantage relative to their matched controls. Furthermore, pseudo-compounds and compounds were somewhat differentially impacted by whether the item was spelled correctly or not. For compounds, both the reaction time and accuracy data indicated that compounds were more easily processed relative to the matched control when the morphemes were readily extracted (i.e., when the word was correctly spelled), but this advantage was removed by the letter transposition. Having a letter transposition at the morpheme boundary led the processing of compounds to be both slower and less accurate, thus removing the compound advantage in processing. Interestingly, for pseudo-compounds, response times were longer than for matched controls in both the correctly spelled and misspelled conditions, but this was statistically significant only in the misspelled condition, as in

Experiment 2. Thus, the letter transposition seemingly enhanced rather than removed the processing disadvantage in terms of speed of processing. However, as was the case for the compounds, the letter transposition decreased the difference between the pseudo-compound and matched control in terms of accuracy, again, as was seen in Experiment 2. It appears, then, that having a letter transposition at the pseudo-morpheme boundary encourages slower, but more accurate, responses for the pseudo-compound words, thus increasing the pseudo-compound processing deficit in response time, but removing it in accuracy.

General Discussion

The current research investigated the role of morphemic processing in compound and pseudo-compound words using a spelling error detection task. Across the three experiments, we find quite consistent results. First, we find clear evidence that compounds and pseudo-compounds both differ from matched control words, strongly suggesting that some form of access of the embedded morphemes occurs. Second, we find that the effects of this access differ markedly for compounds and pseudo-compounds; the access of embedded morphemes appears to decrease the difficulty of processing compound words, but increase the difficulty of processing pseudo-compound words, relative to matched control words. The fact that we observed these deleterious effects for pseudo-compounds strongly suggests that the access of embedded morphemes is obligatory, even when such access is quite unhelpful. Furthermore, the effects of embedded morphology in pseudo-compounds appears to be quite different from what was observed for pseudo-affixed words in that the impact of embedded morphemes for pseudo-affixed words in previous research was beneficial (e.g., Beyersmann, et al., 2016; Longtin, Segui & Hallé 2003; Diependaele et al. 2005). Third, adding a letter transposition at the morpheme boundary clearly attenuates the effect for compound words, but the effect is more equivocal for pseudo-compounds. For pseudo-compounds, the addition of the letter transposition largely removes the accuracy effect, but seems to slightly increase the response time effect of the embedded morphemes. Thus, the current results strongly suggest that morphological processing is attempted, more or less obligatorily, based on the orthographic representation of words. Furthermore, this seems to be true even when attempting morphological processing incurs a processing cost, as in pseudo-compound words.

As described in the Introduction, different theoretical approaches make quite different predictions concerning whether the embedded morphemes should be accessed, and what the results of that access should be on the overall processing of the word. The current data rule out three general approaches. First, any approach that assumes no access of the embedded morphemes, or that assumes access of morphemes only for the compounds, is not consistent with the current set of findings. Second, any approach that assumes simple facilitatory links for all embedded morphemes is also inconsistent. Third, any approach that assumes facilitatory links for compounds and no connections for pseudo-compounds does not explain the current results. The pseudo-compound data seem to require both that the embedded morphemes are accessed and that some form of competition or inhibition occurs when the embedded morphemes in pseudo-compounds are accessed.

Overall, the pattern of data is relatively consistent with our suggestion that all embedded morphemes are accessed (Gagné & Spalding 2009; 2014b; 2014c; 2016; Ji et al., 2011; Spalding & Gagné 2011), but that because this access is part of an obligatory construction process, the embedded morphemes are helpful in processing the compounds but quite unhelpful in processing the pseudo-compounds. We expect this difference in terms of whether the presence of morphemes will help or hinder processing because the embedded morphemes match the actual morphological structure for compounds, but mismatch for pseudo-compounds. The compound items and pseudo-compound items were each used in two experiments (Experiments 1 and 3 for compounds, Experiments 2 and 3 for pseudo-compounds). Across the two experiments containing each kind of item, there are eight individual tests (including the response time and accuracy analyses) for effects of the word structure for compounds and for pseudo-compounds. Eight out of 8 tests show a numerical advantage for compounds relative to their controls, while 7 out of 8 tests show a numerical decrement for pseudo-compounds relative to their controls, with one test showing exactly zero numerical difference. Note that the numerical differences occur quite consistently even though we might expect some attenuation of the effects when the stimuli are mis-spelled. Thus, overall, there is quite strong evidence of the (attempted) use of the embedded morphemes in both compounds and pseudo-compounds, and that this attempted use is helpful for compounds but harmful for pseudo-compounds.

There is one aspect of the data that is not perfectly consistent with this simple picture, and that is the effect of letter transpositions on the pseudo-compounds. The letter transpositions remove the accuracy decrement, but seem to increase the response time decrement, for pseudo-compounds. For compounds, on the other hand, the letter transposition seems to attenuate both the response time and accuracy benefits associated with compound structure, as expected by the simple picture. One possibility is that this is a speed-accuracy trade-off, that happens to occur across the spelling and word type manipulations. However, this pattern is consistent across Experiments 2 and 3. Hence, it is worth considering whether there is a more theoretically interesting way to reconcile the different effects of adding a letter transposition to compounds and pseudo-compounds in terms of the response time and accuracy effects.

To this point, we have only considered the effects of the accessed embedded morphemes matching or mismatching the required structure of the word. However, as described in the Introduction, many theories have separated orthographic and morphological levels of representation and processing (e.g., Crepaldi, Rastle, Coltheart, & Nickels, 2010; Rastle, Davis, & New, 2004). If we assume that there are two levels of representation, we might ask what kinds of effects we should expect from the compounds and pseudo-compounds, and how those effects should be affected by letter transpositions. We can make a few reasonable assumptions about how the system functions. First, the orthographic match involved in having embedded morphemes should ease the orthographic processing of the words (both compound and pseudo-compound), and these effects should attenuate when the letters are transposed. Second, accessing the morphemes should affect morphological processing, making processing easier for compounds and harder for pseudo-compounds, and these effects should also attenuate somewhat when a letter transposition is introduced (assuming that the letter transposition makes it somewhat less likely that the embedded morphemes would be accessed or would push the access later in processing). If the orthographic processing is helped for both compounds and pseudo-compounds, but the effect of the morphological processing is helpful for compounds while also being harmful for pseudo-compounds, then introducing the letter transition can lead to an attenuated overall response time effect for compounds, and can lead to a larger response time decrement for pseudo-compounds because the letter transposition removes the advantage from the orthographic processing.

Imagine, for example, that the orthographic processing in the correctly spelled condition leads to, say, a 50 ms advantage for both compounds and pseudo-compounds. Now imagine that the morphological effect leads to a 100 ms advantage for compounds and disadvantage for pseudo-compounds. This would give, overall, a 150 ms advantage for compounds, but a 50 ms decrement for pseudo-compounds when correctly spelled. When the letter transposition is introduced, it removes (let us assume) the 50 ms advantage for the orthographic processing. This, by itself, would decrease the response time advantage for compounds to 100 ms, but would increase the overall decrement for the pseudo-compounds to 100 ms. Obviously, the numbers here are chosen for convenience, but the pattern would hold as long as the loss of decrement due to the morphological processing was not so big as to completely offset the loss of the orthographic advantage. Clearly this kind of system, across a wide range of specific sizes of the component effects, could lead to the response time patterns that we see in the present experiments.

How would this "two effect" system account for the accuracy results? If we make very similar assumptions as above, we get an advantage for compounds and a disadvantage for pseudo-compounds in the correctly spelled condition. With one additional assumption, we get an attenuation of the effects for both compounds and pseudo-compounds when a letter transposition is introduced. The only additional assumption needed is that part of what leads to the accuracy effects is a tendency to respond that the item is correctly spelled when all of the component information is consistent and to respond that the item is incorrectly spelled when all of the component information is not consistent. Thus, it is important to take into account that accuracy in the correctly spelled condition is saying that the item is correctly spelled, but in the incorrectly spelled condition, saying that it is incorrectly spelled. This matters for the following reasons. When processing a correctly spelled compound, all of the component information (i.e., all the information from the word and from the embedded morphemes) is consistent, so you have a tendency to say that the item is correctly spelled. On the other hand, when processing a correctly spelled pseudo-compound, there is inconsistency (i.e., the embedded morphemes are not really parts of the word), and so there is a tendency to (mistakenly) say the word is incorrectly spelled. This gives an accuracy increase for compounds, but decrease for pseudo-compounds, relative to their controls. However, when the items are incorrectly spelled, the very consistency of the morphological information for compounds leads to a tendency to (mistakenly) say the items are spelled correctly. Similarly, the very inconsistency of the morphological information for the pseudo-compounds leads to a tendency to say that the items are incorrectly spelled, but this response happens to be correct. Hence, the compound advantage in accuracy is attenuated when the letter transposition is introduced, but so is the pseudo-compound decrement in accuracy (in this case, the accuracy effects associated with the orthographic processes are a constant across the word-type manipulation, so we need not take them specifically into account in order to see why we should get the attenuation of the accuracy effects with a letter transposition, except to note that they would tend to create an overall tendency toward accurate responding in all conditions, but would be attenuated in the letter transposition conditions).

The interesting point to note about this more complicated pattern is that so long as there are the two different levels operating as described, the effects observed in both the response time and accuracy analyses can all be generated even though the main effect of adding the letter transposition is still simply to attenuate the two separate effects. The rest of the pattern is generated by the differing directions of the two effects for the different word types, and for accuracy, by the difference in the tendency to respond that the word is correctly or incorrectly spelled. In this sense, this more complicated explanation does not nee7 additional processing mechanisms, compared to the simpler, more general explanation above. Moreover, the general assumption that there are two aspects to processing (i.e., orthographic and morphological) is consistent with other frameworks in the literature.

In general, our results are similar to other recent work investigating compound and pseudo-compound word processing (Gagné & Spalding, 2016; Gagné, Spalding, Nisbet, & Armstrong, 2018) in showing that both kinds of words seem to trigger some form of morphological processing, but that the outcomes of that morphological processing attempt are different. For example, Gagné et al., (2017) found that using the compound or pseudo-compound word as a prime for a constituent or pseudo-constituent led to highly robust priming effects. However, the priming effects were in opposite directions. In particular, the compound word prime led to significant facilitation of the constituent, but the pseudo-compound word prime led to significant inhibition of the pseudo-constituent. In a study of typing latencies (Gagné & Spalding, 2016), compound words and pseudo-compound words both led to differences from control words, showing effects of the morphemic or pseudo-morphemic structure. Again, however, the compound and pseudo-compound words differed from their matched controls in different ways. For example, compound words showed a large elevation in typing time exactly at the morpheme boundary, while pseudo-compound words showed a smaller elevation in typing time, but the elevation began one letter before the pseudo-morpheme boundary, and extended into the second pseudo-constituent, likely due to competition among the activated (potential) morpheme representations and the true representation of the word.

Finally, in terms of the task itself, it is clear that the combination of the spelling error detection task with letter transpositions is a valuable experimental task for investigating morphological processing. The task leads to robust effects (e.g., of word type) with correctly spelled words, and also leads to robust effects with incorrectly spelled words. This task has characteristics that make it a good task to compare with lexical decision, in that correct decisions require the participant to access the intended word, as in lexical decision. However, the spelling error detection task involves a decision process that has some advantages. For one, it is a much more natural task, especially for student populations, but probably for all literate populations: Outside of the laboratory, we are quite commonly required to decide whether something is correctly spelled or not, but are quite rarely presented with letter strings and asked whether or not the string is a word. In addition, comparisons of the different decisions (i.e., correctly vs. incorrectly spelled) in this task are more comparable than in lexical decision tasks (i.e., word vs. non-word), due to the fact that the non-word decision is, by hypothesis, quite open-ended: The participant has to somehow determine that the letter string does not match any word in the lexicon. Our findings suggests that the word access process and the decision process is largely preserved across the correctly and incorrectly spelled words.

Conclusion

The results suggest that some attempt at morphological processing is obligatory, but this processing is only helpful when the true morphological structure of the word matches the apparent morphological structure, as in compounds. When there is a mismatch between the apparent and true morphological structures, as in pseudo-compound words, processing is more difficult. We propose that the findings reflect two effects. First, a orthographic effect that is facilitatory and not sensitive to morphological structure of the whole word. Second, a morphemic effect that is facilitatory for compounds but inhibitory for pseudo-compounds.

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Correspondence concerning this article should be addressed to Christina Gagne, P-217 Biological Sciences Building, Department of Psychology, University of Alberta, Edmonton, Alberta, Canada T6G 2E9. E-mail: cgagne@ualberta.ca

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Table 1

Number of letters, log word frequency (SUBLEX), position of letter switch, bigram frequency, transition probability for Experiment 1

	No error		Spelling error	
	compound	control	compound	control
length (median, range)	8 (6-11)	8 (6-11)	8 (6-11)	8 (6-11)
position of switch (median, range)	4 (3-6)	4 (3-6)	4 (3-6)	4 (3-6)
log word frequency (mean, SE)	1.61 (.06)	1.62 (.06)	n/a	n/a
bigram frequency (mean, SE)	9.80 (.22)	12.28 (.13)	9.62 (.29)	11.31 (.27)
transition probability (mean, SE)	0.027 (.003)	.104 (.008)	.048 (.008)	.07 (.006)

Table 2

Descriptive statistics, means and standard error (RT in ms and Accuracy in %) for Experiment 1

	no spelling error	spelling error
compound	1041 (15)	1269 (18)
	96 (0.5)	90 (0.8)
control	1230 (20)	1354 (22)
	93 (0.7)	85 (0.9)

Table 3

Number of letters, log word frequency (SUBLEX), position of letter switch, bigram frequency, transitional probability for Experiment 2

	No error		Spelling error	
	pseudo	control	pseudo	control
length (median, range)	7 (5-11)	7 (5-11)	7 (5-11)	7 (5-11)
position of switch (median, range)	3 (3-6)	3 (3-6)	3 (3-6)	3 (3-6)
log word frequency (mean, SE)	1.82 (.10)	1.82 (.10)	1.82 (.10)	1.82 (.10)
bigram frequency (mean, SE)	11.68 (.16)	12.23 (.14)	10.91 (.23)	11.49 (.22)
transitional probability (mean, SE)	0.07 (.006)	0.1 (.009)	0.05 (.006)	.07 (.007)

Table 4

Descriptive statistics, means and standard error (RT in ms and Accuracy in %) for Experiment 2

	no spelling error	spelling error
pseudocompound	1067 (18)	1235 (23)
	83 (1.0)	83 (1.1)
control	1058 (19)	1137 (20)
	88 (0.9)	86 (1.0)

Table 5

Descriptive statistics, means and standard error (RT in ms and Accuracy in %) for Experiment 3

	no spelling error	spelling error
compound	967 (13)	1083 (16)
	95 (6)	90 (9)
control for compounds	1100 (20)	1177 (24)
	90 (10)	89 (10)
pseudocompound	1124 (22)	1164 (21)
	83 (11)	89 (10)
control for pseudocompounds	1051 (17)	1074 (20)
	89 (10)	89 (10)

Appendix A

Experiment 1 Materials

Compound Words		Control words	
No Error	Error	No Error	Error
airplane	aiprlane	dynamite	dyanmite
anthill	anhtill	cruises	criuses
backstroke	bacsktroke	expenditure	expnediture
bandstand	bansdtand	utensils	utesnils
bathrobe	batrhobe	crickets	crikcets
battlefield	battlfeield	invitations	invittaions
bearskin	beasrkin	diagrams	diargams
bloodstain	bloosdtain	surrogates	surrgoates
bluebird	blubeird	appliance	appilance
bookshelf	booskhelf	barnacles	barancles
bullfight	bulflight	lavatories	lavtaories
campfire	camfpire	projector	proejctor
checklist	checlkist	libraries	librraies
choirboy	choibroy	mosaics	mosacis
clipboard	clibpoard	hypnotist	hypontist
cloakroom	cloarkoom	tortillas	tortlilas
copyright	copryight	governors	govrenors
crossbar	crosbsar	strollers	strlolers
dockside	docskide	caldron	calrdon
doorbell	doobrell	umbrella	umberlla
driftwood	drifwtood	sculptor	scultpor
earmuff	eamruff	terraces	terarces
eggshell	egsghell	cottages	cotatges
footwear	foowtear	emeralds	emearlds
foxhound	fohxound	mustards	mutsards
grapevine	grapveine	marmalade	marmlaade
gunpowder	gupnowder	envelopes	enevlopes
hairpin	haiprin	steeple	stepele
handshake	hansdhake	particles	paritcles

headache	heaadche	elephant	elehpant
heartburn	hearbturn	camcorder	camcroder
homework	homweork	prisoner	priosner
jailhouse	jaihlouse	escalator	esclaator
junkyard	junykard	churches	chucrhes
keyhole	kehyole	castles	catsles
lamplight	lamlpight	fettucine	fetutcine
landslide	lansdlide	esophagus	esohpagus
lifeguard	lifgeuard	saxophone	saxpohone
lipstick	lisptick	calendar	caelndar
loincloth	loicnloth	cuticles	cutciles
mailman	maimlan	shelves	shevles
matchbox	matcbhox	bassinet	bassniet
mouthpiece	moutphiece	tambourine	tambuorine
noblewoman	noblweoman	canneries	cannreies
nutcracker	nuctracker	pesticides	petsicides
oatmeal	oamteal	lasagna	laasgna
pawnshop	pawsnhop	stapler	stalper
payday	padyay	orchid	orhcid
pickaxe	picakxe	visors	visros
pipeline	pipleine	cucumber	cucmuber
playground	plagyround	journalist	jounralist
pushcart	puschart	steroid	steorid
raindrop	raidnrop	toasters	toatsers
rattlesnake	rattlsenake	auditorium	auditroium
riverbed	rivebred	scallops	scalolps
sailboat	saibloat	asteroid	astreoid
sandpaper	sanpdaper	blinders	blidners
sawdust	sadwust	planter	plnater
schoolgirl	schooglirl	chaperone	chapeorne
seagull	segaull	stomachs	stmoachs
silkworm	silwkorm	cyclones	cycolnes
snowball	snobwall	omelette	omeeltte
soybean	sobyean	textile	tetxile

spacecraft	spacceraft	cosmetics	cosmteics
starfish	stafrish	truffles	truflfes
steamship	steasmhip	editorials	editroials
stingray	stinrgay	squatter	squtater
streetcar	streectar	artifacts	artifcats
tablespoon	tablsepoon	motorists	motoirsts
teargas	teagras	carousal	caruosal
teenage	teeange	burglar	burlgar
tinfoil	tifnoil	auditor	auidtor
tombstone	tomsbtone	vacations	vactaions
warlord	walrord	fiddler	fidlder
watchdog	watcdhog	prophets	prohpets
waterfall	watefrall	catalogue	cataolgue
wheelchair	wheeclhair	destination	destniation
whirlpool	whirplool	guitarist	guitraist
windowsill	windoswill	orangutan	oranugtan
wrongdoing	wrondgoing	figurines	figuirnes

Appendix B

Experiment 2 Materials

Pseudocompound Words		Control words	
Error	No Error	Error	No Error
absorb	abosrb	celery	ceelry
approach	aprpoach	delivery	deilvery
archive	arhcive	widower	wiodwer
armour	aromur	lemons	leomns
bargain	bagrain	chamber	chmaber
begone	beogne	juniper	juinper
betray	bertay	shrimp	shirmp
boolean	boloean	warbler	wabrler
brandish	bradnish	chateaus	chaetaus
brigand	briagnd	caramels	carmaels
candid	cadnid	ravens	raevns
capsize	caspize	bandana	badnana
carpet	capret	statue	sttaue
cartridge	carrtidge	admirers	admriers
cashmere	casmhere	crutches	cructhes
caterpillar	cateprillar	informants	infomrants
chaplain	chalpain	alphabet	alpahbet
chartreuse	charrteuse	developers	deveolpers
consequence	cosnequence	signatures	singatures
corsage	cosrage	staple	stpale
cudgel	cugdel	pinacle	piancle
curfew	cufrew	spiders	spdiers
cutlass	cultass	auditor	auidtor
damask	daamsk	beanies	benaies
denounce	deonunce	licenses	liecnses
disclose	dislcose	journals	jounrals
earnest	eanrest	glucose	glcuose
electrode	elecrtode	smoothies	smoohties
fathers	fahters	festival	fetsival

formations	formaitons	sedatives	sedatvies
fortune	fotrune	sisters	sitsers
galleon	galelon	frittata	fritatta
ganglion	ganlgion	saplings	sapilngs
gigantic	giagntic	dolphins	doplhins
godown	goodwn	ignitor	igintor
heathen	heahten	forests	forsets
hippocampus	hippcoampus	instigators	instgiators
impart	imaprt	rulers	ruelrs
infertile	infetrile	strainer	stranier
kidnap	kindap	drivers	drviers
lacerate	lacreate	granites	graintes
lavatories	lavtaories	delicacies	delciacies
legend	leegnd	dough	doguh
lotion	loiton	marbles	mabrles
malediction	maldeiction	organisers	orgnaisers
mandate	madnate	penguins	pegnuins
massacre	masascre	peaches	peahces
office	ofifce	captain	catpain
pancake	pacnake	tomatoes	toamtoes
pardon	padron	patient	paitent
patriot	partiot	oranges	ornages
pillage	pilalge	chaperon	chaepron
pleasure	plesaure	situation	sitaution
polemic	polmeic	colliers	colilers
portfolio	porftolio	professors	proefssors
prosecute	prosceute	cinnamon	cinnmaon
pumpkin	pumkpin	clothing	clohting
pungent	pugnent	segments	semgents
putrid	purtid	debacle	deabcle
rambling	rabmling	crescent	crsecent
recline	relcine	cerebrum	ceerbrum
sacred	sarced	species	spceies
saturn	sautrn	drains	drians

season	sesaon	engine	enigne
seethe	setehe	geckos	gekcos
sergeant	sergaent	kitchen	kitcehn
shebang	shbeang	snorkel	snrokel
spartan	spatran	titanium	titnaium
sublime	sulbime	prodigy	prdoigy
surfaces	surafces	lecturer	lecutrer
tablet	talbet	helium	heilum
tampons	tapmons	glacier	glcaier
target	tagret	records	reocrds
tawdry	tadwry	acrobat	acorbat
teepee	tepeee	sceptic	scpetic
thousand	thosuand	machine	macihne
thymine	thmyine	vesture	vetsure
vigilante	vigialnte	component	compnoent
visitant	visiatnts	marquees	marqeues
warlock	walrock	referee	reefree

Appendix C

Experiment 3 Materials

Compound Words		Control Words		Pseudocompound Words		Control Words	
No Error	Error	No Error	Error	No Error	Error	No Error	Error
airplane	aiprlane	dynamite	dyanmite	absorb	abosrb	celery	ceelry
anthill	anhtill	cruises	criuses	approach	aprpoach	delivery	deilvery
backstroke	bacsktroke	expenditure	expnediture	archive	arhcive	widower	wiodwer
bandstand	bansdtand	utensils	utesnils	armour	aromur	lemons	leomns
bathrobe	batrhobe	crickets	crikcets	bargain	bagrain	chamber	chmaber
battlefield	battlfeield	invitations	invittaions	begone	beogne	juniper	juinper
bearskin	beasrkin	diagrams	diargams	betray	bertay	shrimp	shirmp
bloodstain	bloosdtain	surrogates	surrgoates	boolean	boloean	warbler	wabrler
bluebird	blubeird	appliance	appilance	brandish	bradnish	chateaus	chaetaus
bookshelf	booskhelf	barnacles	barancles	brigand	briagnd	caramels	carmaels
bullfight	bulflight	lavatories	lavtaories	candid	cadnid	ravens	raevns
campfire	camfpire	projector	proejctor	capsize	caspize	bandana	badnana
checklist	checlkist	libraries	librraies	carpet	capret	statue	sttaue
choirboy	choibroy	mosaics	mosacis	cartridge	carrtidge	admirers	admriers
clipboard	clibpoard	hypnotist	hypontist	cashmere	casmhere	crutches	cructhes
cloakroom	cloarkoom	tortillas	tortlilas	caterpillar	cateprillar	informants	infomrants
copyright	copryight	governors	govrenors	chaplain	chalpain	alphabet	alpahbet
crossbar	crosbsar	strollers	strlolers	chartreuse	charrteuse	developers	deveolpers
dockside	docskide	caldron	calrdon	consequence	cosnequence	signatures	singatures
doorbell	doobrell	umbrella	umberlla	corsage	cosrage	staple	stpale
driftwood	drifwtood	sculptor	scultpor	cudgel	cugdel	pinacle	piancle
earmuff	eamruff	terraces	terarces	curfew	cufrew	spiders	spdiers
eggshell	egsghell	cottages	cotatges	cutlass	cultass	auditor	auidtor
footwear	foowtear	emeralds	emearlds	damask	daamsk	beanies	benaies
foxhound	fohxound	mustards	mutsards	denounce	deonunce	licenses	liecnses
grapevine	grapveine	marmalade	marmlaade	disclose	dislcose	journals	jounrals
gunpowder	gupnowder	envelopes	enevlopes	earnest	eanrest	glucose	glcuose
hairpin	haiprin	steeple	stepele	electrode	elecrtode	smoothies	smoohties
handshake	hansdhake	particles	paritcles	fathers	fahters	festival	fetsival
headache	heaadche	elephant	elehpant	formations	formaitons	sedatives	sedatvies
heartburn	hearbturn	camcorder	camcroder	fortune	fotrune	sisters	sitsers

homework	homweork	prisoner	priosner	galleon	galelon	frittata	fritatta
jailhouse	jaihlouse	escalator	esclaator	ganglion	ganlgion	saplings	sapilngs
junkyard	junykard	churches	chucrhes	gigantic	giagntic	dolphins	doplhins
keyhole	kehyole	castles	catsles	godown	goodwn	ignitor	igintor
lamplight	lamlpight	fettucine	fetutcine	heathen	heahten	forests	forsets
landslide	lansdlide	esophagus	esohpagus	hippocampus	hippcoampus	instigators	instgiators
lifeguard	lifgeuard	saxophone	saxpohone	impart	imaprt	rulers	ruelrs
lipstick	lisptick	calendar	caelndar	infertile	infetrile	strainer	stranier
loincloth	loicnloth	cuticles	cutciles	kidnap	kindap	drivers	drviers
mailman	maimlan	shelves	shevles	lacerate	lacreate	granites	graintes
matchbox	matcbhox	bassinet	bassniet	lavatories	lavtaories	delicacies	delciacies
mouthpiece	moutphiece	tambourine	tambuorine	legend	leegnd	dough	doguh
noblewoman	noblweoman	canneries	cannreies	lotion	loiton	marbles	mabrles
nutcracker	nuctracker	pesticides	petsicides	malediction	maldeiction	organisers	orgnaisers
oatmeal	oamteal	lasagna	laasgna	mandate	madnate	penguins	pegnuins
pawnshop	pawsnhop	stapler	stalper	massacre	masascre	peaches	peahces
payday	padyay	orchid	orhcid	office	ofifce	captain	catpain
pickaxe	picakxe	visors	visros	pancake	pacnake	tomatoes	toamtoes
pipeline	pipleine	cucumber	cucmuber	pardon	padron	patient	paitent
playground	plagyround	journalist	jounralist	patriot	partiot	oranges	ornages
pushcart	puschart	steroid	steorid	pillage	pilalge	chaperon	chaepron
raindrop	raidnrop	toasters	toatsers	pleasure	plesaure	situation	sitaution
rattlesnake	rattlsenake	auditorium	auditroium	polemic	polmeic	colliers	colilers
riverbed	rivebred	scallops	scalolps	portfolio	porftolio	professors	proefssors
sailboat	saibloat	asteroid	astreoid	prosecute	prosceute	cinnamon	cinnmaon
sandpaper	sanpdaper	blinders	blidners	pumpkin	pumkpin	clothing	clohting
sawdust	sadwust	planter	plnater	pungent	pugnent	segments	semgents
schoolgirl	schooglirl	chaperone	chapeorne	putrid	purtid	debacle	deabcle
seagull	segaull	stomachs	stmoachs	rambling	rabmling	crescent	crsecent
silkworm	silwkorm	cyclones	cycolnes	recline	relcine	cerebrum	ceerbrum
snowball	snobwall	omelette	omeeltte	sacred	sarced	species	spceies
soybean	sobyean	textile	tetxile	saturn	sautrn	drains	drians
spacecraft	spacceraft	cosmetics	cosmteics	season	sesaon	engine	enigne
starfish	stafrish	truffles	truflfes	seethe	setehe	geckos	gekcos
steamship	steasmhip	editorials	editroials	sergeant	sergaent	kitchen	kitcehn
stingray	stinrgay	squatter	squtater	shebang	shbeang	snorkel	snrokel

streetcar	streectar	artifacts	artifcats	spartan	spatran	titanium	titnaium
tablespoon	tablsepoon	motorists	motoirsts	sublime	sulbime	prodigy	prdoigy
teargas	teagras	carousal	caruosal	surfaces	surafces	lecturer	lecutrer
teenage	teeange	burglar	burlgar	tablet	talbet	helium	heilum
tinfoil	tifnoil	auditor	auidtor	tampons	tapmons	glacier	glcaier
tombstone	tomsbtone	vacations	vactaions	target	tagret	records	reocrds
warlord	walrord	fiddler	fidlder	tawdry	tadwry	acrobat	acorbat
watchdog	watcdhog	prophets	prohpets	teepee	tepeee	sceptic	scpetic
waterfall	watefrall	catalogue	cataolgue	thousand	thosuand	machine	macihne
wheelchair	wheeclhair	destination	destniation	thymine	thmyine	vesture	vetsure
whirlpool	whirplool	guitarist	guitraist	vigilante	vigialnte	component	compnoent
windowsill	windoswill	orangutan	oranugtan	visitant	visiatnts	marquees	marqeues
wrongdoing	wrondgoing	figurines	figuirnes	warlock	walrock	referee	reefree