Typing time as an index of morphological and semantic effects during English compound processing

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1. Introduction

Words have internal structure and readers often use parts of words to determine word meaning (Graves 2006). Indeed, language-users' awareness of morphemic structure has been linked with enhanced vocabulary growth (Baumann et al. 2002, Brusnighan and Folk 2012; Levin, Carney and Pressley 1988; Wysocki and Jenkins 1987) and reading comprehension outcomes in both developing readers (McCutchen, Logan and Biangardi-Orpe 2009) and university students (Kemp and Bryant 2003). However, precisely how language users make use of morphological structure is not yet known. Moreover, although the role of morphemic structure in comprehension has received increased attention by researchers, the role of morphemic structure in language production is less well-studied. Indeed there has been recent debate as to whether morphemic representations exist (see, for example, Baayen et al. 2011 for a model that does not use morphemes, and Marantz's 2013 response as to why morphemes are essential). In the current project, we examine the role of morphology during the written production of English compounds. Because compound words vary in terms of the semantic transparency of their constituents, we also examine whether the impact of morphology is affected by semantic transparency.

1.1 Involvement of constituent representations

A key empirical and theoretical question in psycholinguistic approaches to this issue has centered on the extent to which representations of the constituents are accessed during the processing of multi-morphemic words. For example, what role do *dog* and *house* play in the representation and processing of the compound word *doghouse*? Theoretical approaches differ substantially in terms of the extent to which morphological structure plays a role in the processing of morphologically complex words (see Kuperman, Bertram, Baayen 2010 for an overview), due to the different emphasis placed on storage and computation.

Although there is no consensus about which particular theory is most viable, empirical findings most strongly support theoretical approaches that allow for morphological decomposition because many studies demonstrate the involvement of subunits in the processing of morphologically complex words. For example, the processing of multi-morphemic words is influenced by the frequency of the constituents (Andrews 1986; Burani, Salmaso and Caramazza 1984; Alegre and Gordon 1999; Baayen, Dijkstra and Schreuder 1997; Bradley 1980; Burani and Caramazza 1987; Colé, Beauvillain and Segui 1989; Meunier and Segui 1999; Niswander, Pollatsek, Rayner 2000; Taft 1979). Also, the more productive a constituent is, as indicated by morphemic family size (i.e., the number of derived and compound words formed from a particular morpheme), the easier it is to process a complex word containing that constituent (Bertram, Schreuder and Baayen 2000; de Jong et al. 2002). In sum, the data are consistent with a maximization-of-opportunity view which posits that the lexical system is highly productive and, during comprehension, actives both whole-word and constituent representations (Libben 2005, 2010).

1.2 Are morphemes involved in language production?

Marantz (2013) provides an overview of the role of morphology in linguistic theory and argues that morphemes are a necessary aspect of language. Most relevant, however, for our research project is the question of whether morphology is used during language production. That is, even though morphemes have been identified by linguists, are these structural units always involved during language processing or are there some situations in which morphemes are not used? Libben (2005, see also Libben and Weber 2014), for example, suggests that some properties of words should be viewed as properties of the state of participants rather than as external entities. That is, linguistic structures might best be thought of as psychological entities rather than as linguistic entities. Therefore, it is useful to examine which structures are involved during language processing as well as factors that might affect the use of such structures.

Psycholinguistic evidence suggesting that language production involves the use of morphemic structures has come from a variety of production tasks including picture naming, handwriting, and typing. For example, the time to name an object in a picture was faster when a morphologically related word was presented on prior trials (Zwitserlood, Bölte, Dohmes 2002); exposure to either the word *rosebud* or *tearose* speeded the naming of a picture of a rose on a subsequent trial. In a subsequent experiment, Zwitserlood et al. (2002) found that the influence of distractors that were both morphologically and semantically related to the picture (e.g., *buttermilk* - *butter*) and distractors that were only morphologically related to the picture (e.g., *butterfly* - *butter*) were nearly identical (cf. Zwitserlood, Bölte and Dohmes 2000). The results suggest that the facilitation was due to the representations sharing a morpheme.

Further evidence comes from the finding that multimorphemic words require more processing time than do monomorphemic words. Roelofs and Baayen (2002) found that preparation time prior to saying a word aloud was longer for Dutch multi-morphemic words (e.g., *bijval*) than for mono-morphemic words (e.g., *bijbel*). Studies that measure latency and movement during handwriting (Pynte, Courrieu and Fenck 1991; Orliaguet and Boë 1993 have also found differences between multimorphemic and monomorphemic words. Orliaguet and Boë 1993 presented a word (e.g., *bois*) in a sentence that supported either the monomorphemic meaning (e.g., *bois* 'wood') or the multimorphemic meaning (e.g. *bois* which is formed from *boi*+ *s* and is the first person singular of 'to drink'). After hearing the sentence, participants wrote the word ten times as their handwriting movements were recorded. Latencies were longer when the word was preceded by the sentence supporting the multimorphemic meaning, which suggests that processing was being affected by the morphemic structure of the word. Kandel, Alvarez, and Vallée (2008) used French suffixed words and found longer delays prior to the writing of a suffix such as -*ette* when it was part of a suffixed word (e.g., *boulette*) than when it occurred in a pseudo-suffixed word (e.g., *goélette*). Similarly, Kandel et al. (2012) found that suffixed words required more processing time than did pseudo-affixed words; the time to produce the letter preceding the syllable boundary was longer for suffixed words than for pseudo-suffixed words and the delay prior to the syllable boundary was longer for suffixed words. In contrast, no differences were observed for prefixed and pseudo-prefixed words. These studies suggest that morphological planning occurs in a serial order (i.e., non-initial morphemes are planned after initial morphemes).

Studies examining typing also show that there are longer delays prior to the morpheme boundary (Sahel et al. 2008; Will, Nottbusch and Weingarten 2006). Furthermore, the type of morpheme affected the size of the increase; Weingarten, Nottbusch and Will (2004) report a study that found that inter-letter typing latencies were longer for digraphs that spanned the boundary of two stem morphemes (e.g., *Korn-ernte* ‘corn harvest’) than between two derivational morphemes (e.g., *an-erkennen* ‘acknowledge’). In sum, previous research using verbal production and written production tasks indicates that morphemes act as planning units during the production of complex words.

An interesting aspect of the effect of morphological complexity is that it slows production (i.e., it introduces delays in the output of complex words), but aids comprehension. For example, in terms of comprehension, Ji et al. 2011 found that lexical decision times were faster for opaque and transparent compounds relative to frequency-matched monomorphemic words. Also, manipulations that enhanced decomposition slowed the processing of opaque compounds and removed the processing advantage provided by complexity. These results were attributed to meaning computation and subsequent competition. That is, when a compound is encountered, it is decomposed into its constituents and the system attempts to combine these constituents to derive a meaning (see, for example, Gagné and Spalding 2009, 2010; Ji, Gagné and Spalding 2011). In the case of opaque compounds, the computed meaning conflicts with the established meaning and processing is slowed as the system attempts to resolve this conflict. Given this difference in comprehension and production, it is important to consider both types of processing to gain better insight into how the language system represents and uses morphological complexity. A question that is particularly relevant is whether meaning competition arises during production.

1.3 Does semantic information affect the involvement of morphology?

Importantly though, compound words vary in the semantic transparency of their constituents. Semantically transparent constituents (e.g., *snow* and *ball* in *snowball*) contribute to the compound’s meaning, whereas semantically opaque constituents (e.g., *hum* and *bug* in *humbug*) do not. Key questions in this field revolve around the relationship between constituent activation and constituents' semantic transparency (e.g., Ji et al. 2011; Libben et al. 2003; Fiorentino and Fund-Reznicek 2009; Marelli et al. 2009; Marelli and Luzzatti 2012; Monsell 1985; Roelofs and Baayen 2002; Sandra 1990; Shoolman and Andrews 2003; Zwitserlood 1994). Do constituent representations become available for all compounds or only for semantically transparent compounds? More specifically, do all constituents' representations become available or do representations only become available for semantically transparent constituents?

Previous research on the comprehension of compounds has shown that the constituents’ representations become activated during the processing of compounds (e.g., Fiorentino and Fund-Reznicek 2009; Sandra 1994; Zwitserlood 1994), and the semantic transparency of these constituents can affect the overall ease with which a compound is recognized (e.g., Libben 2010; Ji et al. 2011). For example, compounds with opaque heads take longer to process than do compounds with transparent heads (Libben et al.2003).

In terms of production tasks, however, the impact of semantic transparency is less clear because studies examining the production of compounds have yielded conflicting results concerning the role of semantic transparency. Roelofs and Baayens (2002) found equivalent performance for production of transparent compound words (e.g., *bijval*), and for opaque complex words (*bijrol*) in a verbal production task, which suggests that morphological complexity is encoded independently of semantic transparency. Consistent with this claim, some researchers have found that opaque and transparent compounds were equally effective at aiding the naming of a picture. For example, Dohmes, Zwitserlood and Bölte (2004) conducted a picture-naming task with distractors using German compounds and found that both opaque and transparent compounds aided picture naming; e.g. *Wildente* (‘wild duck’) and *Zeitungsente* (false report, literally ‘newspaper duck’) aided naming of a picture of a duck to the same extent (see also Luttmann et al. 2011). A similar result was obtained with Dutch compounds; Koester and Schiller (2010) had name a picture (e.g., *ekster*). The picture was preceded by one of several words which participants read aloud. Two of the words were compounds that used the same morpheme as the picture name; the compound was either semantically related to the picture name (e.g., *eksternest* 'magpie nest'), or semantically unrelated (e.g., *eksteroog* literally 'magpie eye' but means 'corn'). The third word (e.g, *gnoom* 'hobgoblin') was morphologically and semantically unrelated to the picture name. In a separate set of items, the picture (e.g., *jas* 'coat') was preceded either by a compound that was morphological related (*jaszak* 'coat pocket'), by a morphological unrelated word (*jasmijn* 'jasmine'), or by related word (e.g., *otter* 'otter'). It took less time to name the picture when it was preceded by the morphologically related primes than by the unrelated prime, and the benefit from the semantically transparent and opaque compounds did not differ. The data point to the involvement of morphemes because mere form overlap (e.g., *jasmijn* prior to *jas*) did not produce a benefit.

In contrast, other studies, using written production, have found effects of semantic transparency. Sahel and colleagues (2008) used a written production task in which participants typed German compounds. There was an elevation in typing time at the morpheme boundary for both semantically transparent and opaque compounds, which suggests that morphology operates without recourse to the meaning of the constituents (see also Aronoff 1994 for a similar claim). However, the latency at the morpheme boundary was affected by semantic transparency for low frequency compounds such that the latency was shorter for opaque compounds than for transparent compounds, which suggests that morphological planning can be affected by semantic transparency. Libben and Weber (2014) examined typing times for English compounds that varied in the transparency of the first and second constituent. They found that the latency increase at the morpheme boundary was smaller for opaque-opaque (OO) compounds than for transparent-transparent (TT) and opaque-transparent (OT) compounds. The increases in typing time at the boundary for OO and transparent-opaque (TO) compounds were statistically equivalent.

In sum, it appears that the lexical representations of compounds are morphologically structured, but it is not yet known the extent to which semantic transparency impacts the production of compound words. Some studies indicate that processing system is sensitive to morphemic structure irrespective of semantic transparency, whereas others have found that the impact of morphemic structure is greater for transparent compounds than for opaque compounds.

1.4 Aim and Overview of the Experiments

We conducted two experiments using a progressive demasking (PDM) paradigm (Grainger and Segui 1991). In this task, the stimulus is initially obscured on the computer screen then gradually becomes more visible. Combined with the PDM task, we examined inter-letter typing speed by having participants type the word after it had been identified. The typing task allows us to measure how much time is spent in different regions of a word (Libben, Weber and Miwa 2012; Libben and Weber 2014; Sahel et al. 2008; Will et al. 2006) and, thus, is particularly useful for identifying the extent to which morphemes are involved in the processing of the word. If participants are sensitive to a word's morphological structure, then we should observe elevated typing times at the morpheme boundary (see Libben 2011). To illustrate, the typing time for the letter *h* in the word *doghouse* should be longer than for the preceding letter (e.g., *g*) because it is the start of the second morpheme.

In addition to examining the role of morphology on written production, we examined the possible involvement of semantic information in two ways. First, we manipulated semantic transparency. In both experiments we varied the transparency of the first constituent while holding the transparency of the second constituent constant so that we were able to compare the impact of having a transparent versus an opaque first constituent. In Experiment 1, the head (i.e., second constituent) of the compound was semantically transparent, whereas in Experiment 2, the head was opaque.

Second, we manipulated the availability of the meaning of the first constituent by preceding the presentation of the compound (e.g., *strawberry*) with a word that is either semantically related (e.g., *hay*) or unrelated (e.g, *pine*) to the first constituent (e.g, *straw*). This manipulation allows us to examine whether emphasizing the meaning of a constituent causes processing difficulty for compounds with semantically opaque constituents.

In sum, the specific aims of the current set of experiments was to examine the role of morphological structure on written production, to assess whether the availability of the meaning of the first constituent influences the written production of a compound, and to determine whether the influence of priming depends on the semantic transparency of the first and second constituents.

2. Experiment 1

Previous research (e.g., Libben et al. 2003; Marelli and Luzzatti 2012; Marelli et al. 2014) found that the semantic transparency of the head noun influenced the processing of compounds. In the current experiment, we focus on compounds with transparent heads.

2.1 Methods

2.1.1 Materials and design

Eight-eight compound words with transparent heads (second constituents) were used. The compounds varied in terms of the semantic transparency of the first constituent such that half the items had an opaque first constituent (e.g., *strawberry*) and half had a transparent first constituent (e.g. *soupspoon*). Two primes were selected for each compound based on the relatedness to the first constituent of the compound. The related prime (e.g., *hay* for *strawberry*) was selected using Latent Semantic Analysis (LSA) scores (Landauer 2002; Landauer and Dumais 1997) and the unrelated prime (e.g., *pine* for *strawberry*) was selected from the SUBTLEXus database (Brysbaert and New 2009) by searching for words that matched the related prime in terms of word length and word frequency (within 10% of the frequency per million measure).

2.1.2 Procedure

Each trial began with the message “Ready?” on the computer screen and participates initiated the trial by pressing the space bar. Next, the prime and target were presented using a Progressive Demasking technique (PDM) in which a stimulus slowly becomes visible. Initially, a mask (which was a row of hash marks, ##########) was displayed followed by a brief presentation (40 ms) of the prime. Next, a mask was displayed followed by the target (i.e., the compound). The duration of the mask-target remained constant at 1015 ms, but the display time of the target increased relative to the display time of the mask. During the first cycle, the mask was displayed for 1000 ms and the target for 15 ms. This sequence was repeated with the presentation of the target being increased by 15 ms and the presentation of the mask being decreased by 15 ms for each sequence. From the participants’ perspective, the target appears to emerge from the mask. Participants press a computer key as soon as they have identified the word. Next, participants typed the word that they had identified and the computer recorded inter-letter typing latency. Inter-letter typing latency is the time between the onset of typing one letter and the offset of typing the subsequent letter and can be used to examine which subunits are involved in word production (see Libben et al. 2012; Libben and Weber 2014; Sahel et al. 2008). Our main variable of interest was inter-letter typing latency at various parts of the word.

2.1.3 Participants

All participants in the current experiment and following experiments spoke English as their native language. Fifty-four introductory psychology students at the University of Alberta participated for course credit. The data from eight participants were excluded due to high error rates. Thus, the analyses that we report are based on 46 participants.

2.2 Results and discussion

The data was analyzed using Linear Mixed Effects (LME) models (see Baayen, Davidson and Bates 2008; Pinheiro and Bates 2000) using the *mixed* function in Stata 13. In all models, subject and items were used as random factors. The dependent variable, typing latency, was log-transformed to reduce skewness.

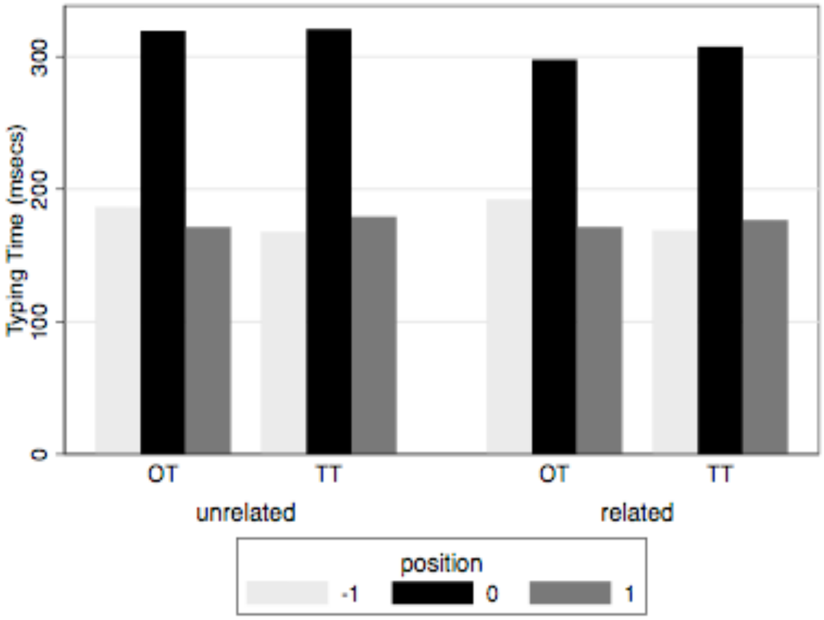
We performed separate sets of analyses which each targeted a specific region of the word. We looked for differences in typing time just before and just after the morpheme boundary. We also conducted separate analyses to examine the initiation time for the first and the second constituents.

2.2.1. Morpheme boundary effect

To examine whether there was evidence of the use of morphology during written production, we compared the typing time for the letter before and at the boundary; e.g., for the word *strawberry* we compared the times for typing the letters *w* and *b*. As indicated in Figure 1, typing time was elevated at the first letter of the second constituent relative to the preceding letter, $z = -22.57$, $p < .0001$, which indicates that participants were sensitive to morphology. Typing times were also affected by semantic information; the influence of position (i.e., before v.s. at the boundary) interacted with prime (i.e., semantically related vs. unrelated), $z = 2.17$, $p = .03$, and with the semantic transparency of the first constituent, $z = -2.84$, $p = .005$.

Subsequent analyses of these two interactions revealed that the increase was larger in the semantically unrelated prime condition than in the related prime condition, $z = 2.07$, $p = .04$; the prime affected the time to type the letter at the boundary (i.e., at the first letter of the second constituent), $z = -2.38$, $p = .02$, not at the letter prior to the boundary, $z = .55$, $p = .58$. This result suggests that increasing the meaning of the first constituent might lead to the morphemic representation of that constituent being more strongly available which in turn boosts the activation of the entire morphemic structure. For example, exposure to the word *hay* activates related words, including the word *straw*. The increased availability of the meaning of *straw* increases the availability of the morpheme *straw* on its own as well as its representation in the word *strawberry*. This makes it easier for the production system to make use of the morphological structure for *strawberry*.

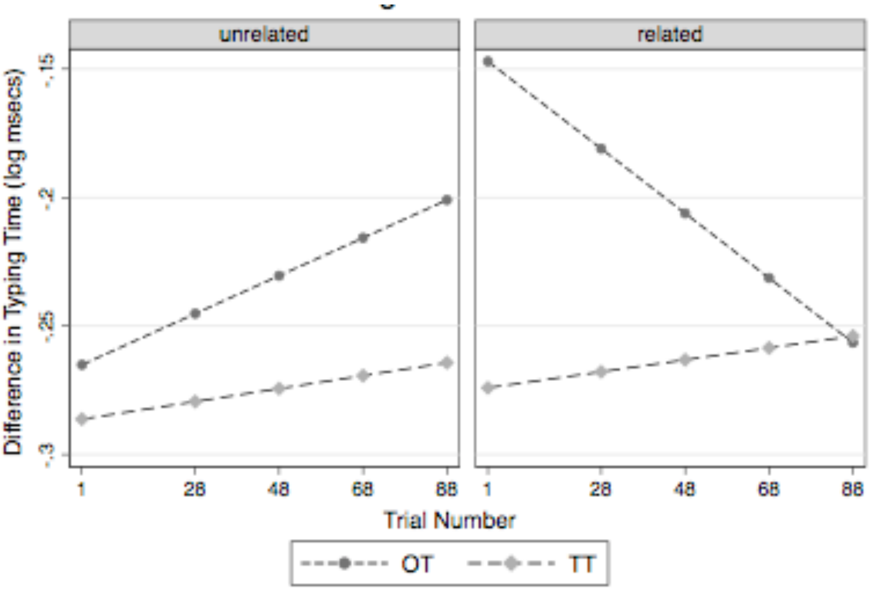
Figure 1: Typing time for letters before, at, and after the morpheme boundary in Experiment 1



Our analyses also revealed that the increase in typing time at the boundary was larger for TT compounds than for OT compounds, $z = -5.00$, $p < .0001$. This increase was due to an effect of first constituent's semantic transparency at the pre-boundary position, $z = -2.76$, $p = .006$. There was no effect of the first constituent's transparency at the boundary, $z = .91$, $p = .36$. In other words, typing time at the pre-boundary position (e.g., at the end of the first constituent) was faster for compounds with transparent first constituents than for compounds with opaque first constituents, but the typing time for the first letter of the second constituent was equivalent for TT and OT compounds. This result indicates an impact of semantic transparency in that opaque constituents take longer to type than do transparent constituents.

In a separate set of analyses, we examined whether the boundary effect changes across the experiment. To do this, we included trial number as a predictor variable in the model and examined whether it interacted with the other variables. There was a four-way interaction between prime, compound type, position (pre vs. post boundary) and trial, $z = 2.44$, $p = .02$. Figure 2 shows the difference in typing time before and at the boundary across trial. As can be seen in this graph, the boundary effect was influenced by prime type and by compound type. Overall, the boundary effect was larger for OT compounds than for TT compounds and this effect was relatively consistent across the experiment (i.e., the effect does not greatly change from the first trial of the experiment to the last trial). However, in the related prime condition, the boundary effect was much greater for OT compounds than for TT compounds for early trials, but the effect was equivalent for OT and TT compounds at later trials; during the course of the experiment, the boundary effect was reduced for OT compounds. These findings indicate that the production system adapts across the course of the experiment.

Figure 2: Difference in typing time for the letter before and after the morpheme boundary in Experiment 1

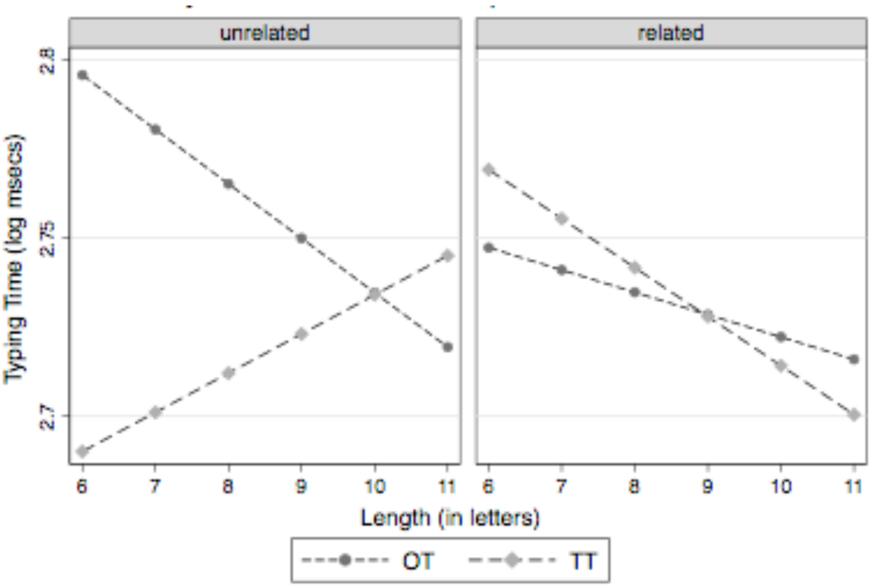


2.2.2 Typing latency for the first letter of the first constituent

We found an influence of semantic information on the production of the first constituent. The LME model indicated that the time to initiate typing the word (i.e., the typing time for the first letter of the first constituent) was affected by prime, *z* = -2.28, *p* = .02, as well as by compound type, *z* = -2.42, *p* = .02, and these two variables did not interact with each other, *z* = 1.67, *p* = .10. Overall, OT compounds took more time to initiate than did TT compounds.

Because the compounds varied in length, we also conducted analyses that included length (i.e. number of letters) as a predictor variable. As illustrated in Figure 3, there was a three-way interaction between prime, compound type, and length, *z* = -2.56, *p* = .01, and thus we decomposed this interaction. The effect of length differed depending on whether the compound was preceded by a semantically related or unrelated prime and on the semantic transparency of the first constituent. The effect of length was equivalent for the OT and TT compounds in the related prime condition, *z* = -.68, *p* = .49, but was greater for the TT than for the OT compounds in the unrelated prime condition, *z* = 2.38, *p* = .02.

Figure 3: Typing time for the first letter of the first constituent in Experiment 1

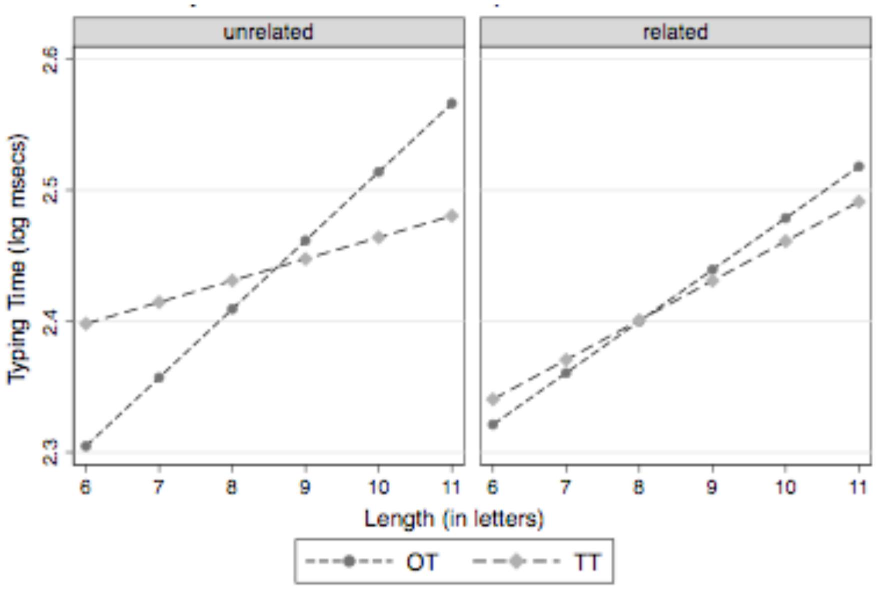


Another way to describe the three-way interaction is that influence of the prime and length differed depending on compound type. For the TT compounds, prime and length interacted, *z* = -2.56, *p* = .01, such that in the unrelated prime condition typing latency was unaffected by length, *z* = 1.37, *p* = .17, whereas in the related prime condition typing latencies showed a trend to be faster for longer words than for shorter words, *z* = -1.73, *p* = .08. The OT compounds showed a different pattern in that prime did not interact with length, *z* = .98, *p* = .33; typing latency was faster in the related condition than in the unrelated condition regardless of length, *z* = -2.01, *p* = .04.

2.2.3 Typing latency for the first letter of the second constituent

Time to initiate typing the second constituent was affected by Prime, z = -2.31, p = .02, but not by compound type, z = .62, p = .54.

Figure 4: Typing time for the first letter of the second constituent in Experiment 1



However, the influence of compound type was evident once stimulus length was included in the model. As illustrated in Figure 4, there was a three-way interaction between prime, compound type, and stimulus length, z = 2.28, p = .02. Both compound types showed an increase in typing time for longer words than for shorter words; z = 4.99, p < .001 for OT compounds and z = 2.40, p = .02 for TT compounds. However, the prime differentially affected the impact of length depending on compound type. In the unrelated prime condition, the impact of length was greater for OT compounds than for TT compounds, z = -2.45, p = .01, whereas in the related prime condition, the impact of length was equivalent for OT and TT compounds, z = -.63, p = .53.

2.3 Summary of results

Consistent with previous results reported by Libben and colleagues (Libben et al. 2012; Libben and Weber 2014), we find an morphemic boundary effect in that the inter-letter latency is longer at the boundary than before the boundary. In addition, we find that semantic information (both in terms of semantic transparency and of semantic priming) influenced production. For example, the size of the morphemic boundary effect was affected by prime and by semantic transparency. Conversely, the effects of semantic transparency differed depending on morphemic region. For example, in the unrelated prime condition, the impact of length was greater for TT compounds than for OT compounds during the initiation of the first constituent, but the reverse was true during the initiation of the second constituent.

In terms of the initiation of the first constituent, OT compounds slowed production relative to TT compounds. In terms of the initiation of the second constituent, the impact of compound type was dependent on prime type and on stimulus length; there was no difference between TT and OT compounds in the related prime condition, whereas in the unrelated prime condition, stimulus length influenced whether TT or OT compounds were produced more quickly.

3. Experiment 2

Experiment 1 showed that written production was influenced by morphemic structure and by semantic information (i.e., by semantic transparency and by the availability of the meaning of the first constituent). In the current experiment, we examine whether these factors influence the production of compounds with opaque heads.

3.1 Methods

3.1.1 Materials and design

One hundred compound words with opaque heads (second constituents) were used. As in Experiment 1, the items varied in terms of the semantic transparency of the first constituent. Half the items had an opaque first constituent (e.g., *pineapple*) and half had a transparent first constituent (e.g. *jailbird*). Two primes were selected for each compound; one was semantically related to the first constituent (e.g., *crime* is related to *jail*) and one was unrelated (e.g., *books* is unrelated to *jail*). The primes were selected using the same procedure as described in Experiment 1.

3.1.2 Procedure

The procedure was identical to one used in Experiment 1.

3.1.3 Participants

Forty-four introductory psychology students at the University of Alberta participated for course credit. The data from one participant was removed prior to analysis due to a computer malfunction during data collection and another due to a visual impairment. The data from an additional nine participants were excluded due to high error rates. Thus, the analyses that we report are based on 33 participants.

3.2 Results and discussion

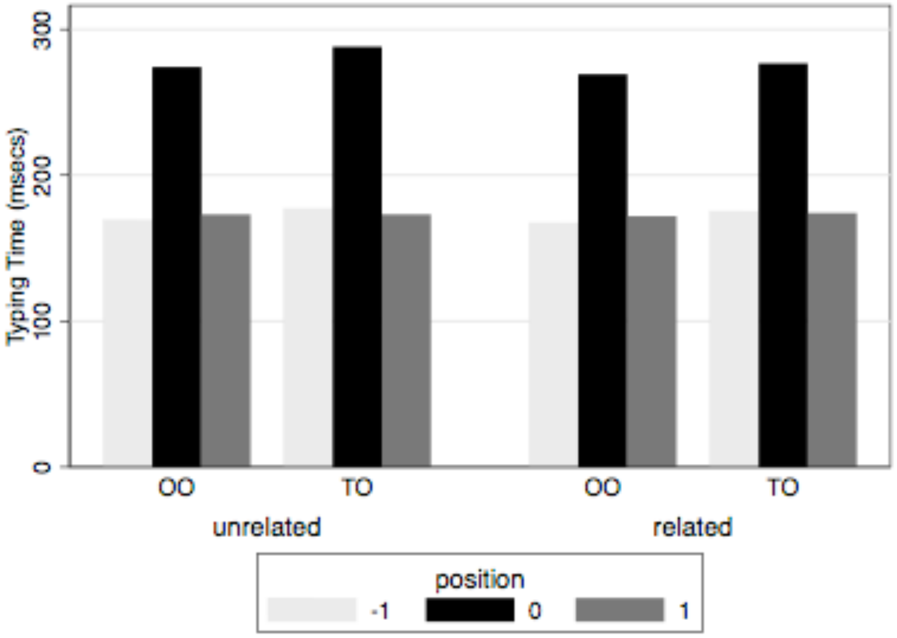
We used the same analysis strategy as for Experiment 1, in which we conducted separate analyses for each morphemic region. Our dependent variable was log-transformed typing latency.

3.2.1 Morpheme boundary effect

As indicated in Figure 5, typing time was elevated at the first letter of the morpheme boundary relative to the preceding letter, $z = 19.85$, $p < .0001$. However, unlike in Experiment

1, the difference between typing latency for the letter before and at the boundary was not affected by prime, *z* = .41, *p* = .68, nor by compound type, *z* = .21, *p* = .84. As in Experiment 1, we conducted a separate analysis to determine whether the boundary effect changed across the experiment. However, trial did not interact with any of the other variables, all *p*'s > .30.

Figure 5: Typing time for letters before, at, and after the morpheme boundary in Experiment 2



3.2.2 Typing latency for the first letter of the first constituent

As in Experiment 1, we used prime (related vs. unrelated), compound type (OO vs. TO), and length as predictor variables in the model. Unlike Experiment 1, these three variables did not interact, *z* = -.22, *p* = .83, nor were there any two-way interaction involving these variables. Therefore, we considered a simpler model that included the variables without any interaction terms. In this model, typing times for TO compounds were faster than for OO compounds, *z* = -2.35, *p* = .02, and neither prime (*z* = 1.14, *p* = .26) nor length (*z* = 1.46, *p* = .14) were valid predictors. It took more time to initiate typing of OO compounds) than of TO compounds.

3.2.3 Typing latency for the first letter of the second constituent

Prime, compound type, and length did not interact, *z* = -.28, *p* = .78, nor were there any two-way interaction involving these variables. A model without any interaction terms indicated that time was not affected by compound type (*z* = .29, *p* = .77) nor by prime (*z* = .45, *p* = .65). However, there was a trend for typing times to be longer for longer compounds than for shorter compounds, *z* = 1.83, *p* = .07.

3.3 Summary of results

Morphemic structure influenced written production; inter-letter latency increased at the morphemic boundary and the impact of various semantic variables depended on morphemic region. The initiation of the first constituent was affected by the semantic transparency of the first constituent, whereas the initiation of the second constituent was not affected by this variable.

4. General Discussion

Linguists have identified several levels of structure within language, and psycholinguists have sought to identify which structures affect processing of language. In this sense, the psycholinguistic data is used to determine which types of linguistic structures are used by language users (for a discussion of the role of psychocentricity in arbitrating which linguistic constructs are psychologically valid, see Libben and Weber 2014). In the case of compounds, debate has continued over whether the morphemes of semantically opaque constituents are involved in processing. Our data contribute to the ongoing discussion by illustrating that morphemic structure is involved in written production, even for opaque compounds, and that semantic transparency also plays a role.

The typing task was useful for examining these issues because it is a natural task (for our participant population) in that it is something that the participants engage in everyday. Also, this task does not require the use of filler materials (such as nonwords). Even though typing is highly practiced, it still is sensitive to the variables that we manipulated. The primary advantage of the typing task is that we can get processing measures at specific regions within the word to determine whether morphology affects ease of processing.

The increase in typing latency at the morpheme boundary suggests that written production for English compounds relies on structured representations. If unitary representations (i.e., whole-word representations) were used, then there would be no increase at the boundary. Furthermore, the nature of the structures appears to be morphemic rather than semantic because we found a robust morphemic boundary effect regardless of the transparency of the head nouns and of the modifiers. Thus, our results are consistent with previous claims in the literature that morphemes act as planning units during production (Koester and Schiller 2008; Roelofs 1996; Roelofs and Baayen 2002). In particular, people appear to be planning the production of compound words in terms of their morphological units. They output the first constituent and then re-access the morphemic structure of the compound to obtain the structure corresponding to second constituent, which introduces a brief delay between the two constituents in terms of inter-letter typing latency. This interpretation is consistent with previous research involving typing and handwriting (e.g., Kandel, Alvarez, Vallée 2006; Libben and Weber 2014; Sahel et al. 2008) that also found processing delays at morpheme boundaries.

The priming effect observed in Experiment 1 also suggests that the use of morphemic structures is independent of semantic information (see Roelof and Baayen 2002 and Koester and Schiller 2008 for a similar conclusion) because boosting the availability of the first constituent (via the related prime) affected written production even when the meaning of that constituent was unrelated to the meaning of the compound (i.e., when the first constituent was opaque). For example, both *straw* and *berry* were easier to initiate when *hay* was briefly presented prior to the compound (i.e., *strawberry*) even though *straw* is semantically opaque. This suggests that the locus of the semantic priming effect ultimately was not semantic in nature but rather morphemic. Furthermore, boosting access to the first constituent of the compound's morphemic structure also benefited access to the second constituent within that structure.

As noted in the Introduction, there has been conflicting evidence in the literature concerning the effects of semantic transparency. Our results contribute to that debate by providing several pieces of evidence that demonstrate effects of semantic transparency. First, we found that opaque first constituents appear to produce processing difficulties, particularly when the second constituent was also opaque; compounds with opaque first constituents took longer to initiate then did compounds with transparent first constituents. This suggests that the processing system is sensitive to the semantic transparency of the constituents. It could be the case that opaque constituents take more time to access because the semantic representation is not linked to the representation of the whole compound (as suggested by Zwitserlood 2004), or it could be that the semantic representation of opaque constituents must be suppressed (see, for example Ji, Gagné and Spalding 2011) and that this suppression takes processing resources, which slows production.

Second, the semantic transparency of the second constituent altered the impact that the prime had on written production. When the head of the compound was transparent (as in Experiment 1), the boost provided by the related prime to the morphemic representation of the first constituent aided the production of both constituents by making the morphemic structure of the entire compound easier to access. However, when the head of the compound was opaque (as in Experiment 2), the prime did not yield this benefit in processing, even when the first constituent was semantically transparent. We propose that emphasizing the morphemic structure for compounds with opaque heads increased conflict among potential meanings for the compound because the computed, literal, meaning of the compound is not of the same category as the conventional meaning. For example, the conventional meaning of *hogwash* (e.g., nonsense) is very different from computed meaning (e.g., a wash for hogs) This competition must be resolved and offsets the benefit of the related prime (see El-Bialy, Gagné and Spalding 2013 and Ji et al. 2011 for other research that has found competition-based processing difficulties for opaque compounds).

Finally, the semantic transparency of the second constituent also influenced the way in which semantic transparency of the first constituent and prime interacted. For example, the size of the boundary effect was affected by the prime only when the head was semantically transparent (i.e., in Experiment 1). Also, when the head was transparent, the impact of length was greater for TT compounds than for OT compounds during the initiation of the first constituent in the unrelated prime condition, but the reverse was true during the initiation of the second constituent. This pattern was not observed when the head was opaque. Similarly, the related prime condition removed the processing advantage for compounds with transparent first constituents in that there was no difference in typing time for the start of the second constituent for TT and OT compounds. These results indicate that written production is sensitive to semantic transparency.

The observation that the priming effect that was obtained in Experiment 1 did not occur when head was opaque (i.e., in Experiment 2) is consistent with research by El-Bialy et al. (2013) that found that the priming effect in a lexical decision task depended not only on the transparency of the constituent that was being targeted by the prime, but also on the semantic transparency of the other constituent. This finding is consistent with the suggestion that semantic transparency might be a psychological property rather than strictly a linguistic property (see Libben 2005; Libben and Weber 2014); the effect of transparency is not constant across constituents and across priming conditions. That is, the influence of transparency depends on the processing context. Similarly, the data indicate that the two types of semantic information that we manipulated (i.e., semantic transparency and activation of the meaning of the first constituent) produced different effects, which indicates that the nature of semantic priming is different from the nature of semantic transparency and that the influence of transparency differs depending on the extent to which the meaning of the first constituent is available.

Taken together, our data indicate that morphemic structures are involved in the production of English compounds but that semantic transparency and the availability of the meaning of the first constituent also play a role. Although our results point to the involvement of both morphemic and semantic information, the way in which these sources of information are used appears to be complex in that the influence of the variables frequently interacted. Thus, it is not surprising that the literature concerning the role of semantic transparency has not yet yielded a clear consensus. We propose that the semantic transparency of each constituent must be considered in order to obtain a clearer picture of what is occurring during the use of the morphemic structures associated with compound words.

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