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Compound fracture: The role of semantic transparency and morphological headedness☆

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Abstract

This paper explores the role of semantic transparency in the representation and processing of English compounds. We focus on the question of whether semantic transparency is best viewed as a property of the entire multimorphemic string or as a property of constituent morphemes. Accordingly, we investigated the processing of English compound nouns that were categorized in terms of the semantic transparency of each of their constituents. Fully transparent such as *bedroom* are those in which the meanings of each of the constituents are transparently represented in the meaning of the compound as a whole. These compounds were contrasted with compounds such as *strawberry*, in which only the second constituent is semantically transparent, *jailbird*, in which only the first constituent is transparent, and *hogwash*, in which neither constituent is semantically transparent. We propose that significant insights can be achieved through such analysis of the transparency of individual morphemes. The two experiments that we report present evidence that both semantically transparent compounds and semantically opaque compounds show morphological constituency. The semantic transparency of the morphological head (the second constituent in a morphologically right-headed language such as English) was found to play a significant role in overall lexical decision latencies, in patterns of decomposition, and in the effects of stimulus repetition within the experiment.

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1. Introduction

There is mounting evidence that the notion of semantic transparency is crucial to the understanding of the manner in which multimorphemic words are represented in the mind. Semantic transparency sets boundary conditions on whether a multimorphemic word can be comprehended in terms of its constituent morphemes or whether it must have its own representation in the mental lexicon. To illustrate, a compound such as *car-wash*, would be easily comprehended by someone who had never heard the word before, whereas the compound *hogwash* requires an independent entry in the mental lexicon in order for its idiosyncratic meaning 'nonsense' to be comprehended. The compound *car-wash* can therefore be described as semantically transparent because the meaning of the entire string can be derived from the combination of the meanings of its constituents. It is also possible to derive a meaning for *hogwash* based on its constituents *hog* and *wash*, but this computed meaning will not be consonant with the idiosyncratic 'normal' meaning of the compound. It is therefore appropriate to refer to *hogwash* as semantically opaque.

The centrality of the notion of semantic transparency in the processing of multimorphemic words has been evident in a number of recent psycholinguistic investigations (see McQueen & Cutler, 1998). Laudana and Burani (1995) claimed that semantic transparency determines whether a multimorphemic string is processed via a whole-word recognition route or through a route that employs morphological decomposition. Marslen-Wilson, Tyler, Waksler, and Older (1994) report findings that also support the importance of semantic transparency. They found significant whole-word constituent priming effects for semantically transparent affixed forms such as *insincere* and *punishment* but not for semantically opaque forms such as *restrain* and *casualty*. Finally, Schreuder and Baayen (1995) present a meta-model of morphological processing in which semantic transparency determines to a large extent whether a multimorphemic form has its own representation in the mental lexicon or whether it is represented in terms of its constituents.

The reports cited above are diverse in their underlying assumptions and theoretical orientations. Yet they converge on the claim that any model of the representation of multimorphemic words in the mind will have to include an account of how semantic transparency is represented and the role that it plays in word recognition. In this paper, we explore this role through the representation and processing of English compounds and claim that compounds offer an important testing ground for the study of semantic transparency and its role in the organization of the lexicon.

2. Transparency and morphological decomposition

In the examples *car-wash* and *hogwash* above, we noted that in the case of *car-wash*, comprehension would be possible through a mechanism of morphological decomposition, whereas in the case of *hogwash*, a morphological decomposition procedure would not yield the correct compound meaning. This basic observation leads to the experimental prediction that a difference between semantically transparent and nontransparent compounds should be observed in a task that is sensitive to the effects of morphological decomposition. This prediction was investigated by Sandra (1990) who employed a semantic priming paradigm in which semantic associates of constituents served as primes and full compounds served as targets. His study compared lexical decision latencies for semantically transparent compounds (e.g., *birthday* primed by *death*) to those for semantically opaque compounds (e.g., *Sunday* primed by *moon*). Sandra reasoned that if recognition of a compound was achieved though a morphological parsing procedure that first activated a compound's constituents, a constituent semantic priming effect should be observed. On the other hand, if a compound is accessed as a whole unit or if constituent activation only occurs after the whole word is accessed, then priming the constituents would have no faciliatory effect on compound recognition and hence on lexical decision latencies. The main results of Sandra's experiments were that only semantically transparent compounds showed priming effects. He therefore concluded that only semantically transparent compounds are processed through a morphological decomposition procedure.

Sandra's findings raise a concern about the nature of the process through which constituents of a compound can be activated. In the case of affixed words, it has been broadly assumed that morphological decomposition takes place through the removal of affixes from a stem (see Taft, 1981). Because affixes comprise a closed-class set in the language, it has also been assumed that these could be 'looked up' in a short list. However, since compounds are composed of two or more roots, the 'short list' approach will not work for these stimuli. This problem is addressed in Libben (1994) who proposed a left-to-right morphological parsing procedure that does not search for affixes but, rather, simply exposes substrings of a multimorphemic word in a successive manner. Libben (1994) claims that apparent effects of prefix-stripping emerge in the model as a consequence of the left-to-right nature or morphological parsing, which he represents as a series of discrete steps in which multiple parses are handled through a process of recursion. The framework further assumes that the effect of semantic transparency is not found at the level of morphological parsing but rather at the level of lexical representation. At this level, semantic transparency may be represented as the presence or absence of associations between the lexical representation of the compound and the lexical representation of the constituents (see Libben, 1998). Thus, for compounds, it is necessary to assume that all existing multimorphemic strings will have their own representations in the mental lexicon regardless of their degree of semantic transparency. This is one of the ways in which compounds in a language such as English might be quite different from affixed forms. In the case of inflectional suffixes such as *-ing* in English, it is possible to claim that the meaning of the multimorphemic string (e.g., *chewing*) is entirely recoverable from the meanings of its constituents. This might also be the case for some derived suffixed forms (e.g., *chewable*) and derived prefixed forms such as *re-tie*. However, it seems never to be the case that the meaning of an existing compound can be completely predicted from the meanings of its constituents. Consider, for example, the compounds *football*, *baseball*, and *volleyball*. In all of these, there are clearly links between the meanings of the constituents and the meanings of the compounds. However, in no case would it be possible to derive the meaning of the compounds solely from their constituents.

Another salient characteristic of compounds concerns the operationalization of semantic transparency. Note that in the two examples we have used so far, *car-wash* and *hogwash*, semantic transparency has turned out to be an all-or-none phenomenon. In the case of *car-wash*, both constituents are linked to the compound, whereas in the case of *hogwash* neither constituent is linked to the compound. The compound *hogwash* is therefore an extreme case of semantic opacity, and perhaps an unrepresentative one as well. If we return to the types of semantically opaque stimuli used by Sandra (1990) (e.g., *Sunday*), we see that it is only the initial constituent that is opaque. In other words *Sunday* is a type of day, but *hogwash* is not a type of wash. Recent experimentation by Zwitserlood (1994) has suggested that the distinction between partially opaque and fully opaque compounds has consequences for their representations in the mental lexicon and for their behavior in priming experiments.

In fact, she used this distinction to account for some of the discrepancies between her results and those of Sandra (1990).

To summarize to this point, there is overwhelming evidence that semantic transparency plays an important role in the representation of multimorphemic words. In the case of compounds, an understanding of semantic transparency requires an additional consideration of whether all, one, or no constituents are linked to the whole word. The experiments that we report in this paper were designed to address this consideration and therefore to investigate whether transparency is most profitably seen as a property of individual morphemes or a property of multimorphemic forms.

3. A classification of compound transparency

The compound processing experiments that we describe in this paper were organized around a particular classification of English noun–noun and adjective–noun compounds that promised to be revealing of the role of constituent, positional, and whole-word factors. This classification characterized bimorphemic compounds as belonging to one of four groups-representing all possible combinations of the relationship of a constituent's meaning within a compound and its meaning as an independent lexical form. These four groups are:

TT (transparent–transparent) (e.g., *car-wash*)
OT (opaque–transparent) (e.g., *strawberry*)
TO (transparent–opaque) (e.g., *jailbird*)
OO (opaque–opaque) (e.g., *hogwash*)

Breaking down compounds in this fashion allows us to explore in a more fundamental way the underlying nature of semantic transparency. If, for example, transparency is simply a matter of the relationship between the meanings of morphemes in a compound and their meanings as independent lexical items, then we should find three degrees of processing effects—one for fully transparent items (TT), one for partially transparent (OT and TO) items, and one for fully opaque (OO) items. If these degrees of transparency also interact with a morpheme's position in a compound, then we should expect additional distinctions between OT and TO compounds. Exploring this possibility allows us to investigate whether the head of a compound (the rightmost element) enjoys a special processing status.

To summarize, then, if properties of individual morphemes are at the basis of semantic transparency effects and if these effects are greatest for morphemes that function as morphological heads, then we should expect that TT compounds should show the greatest transparency effects, followed by OT, TO, and OO stimuli. If, on the other hand, compounds with any opaque element are properly described as opaque then TO, OT, and OO compounds should pattern together and be distinguished from TT. Finally, it could be the case that compounds with any transparent element are represented as having constituent structure in the mental lexicon. In this case TT, TO, and OT compounds would pattern together and be distinguished from OO compounds.

3.1. The core stimuli

Forty TT, OT, TO, and OO compounds served as core stimuli in our experiments. This set was created from an initial list of 116 compounds that were selected as falling most clearly into one of the four groups. Items in the initial set were balanced across categories for constituent frequency, compound frequency and length. All stimuli were adjective–noun or noun–noun compounds and, with the exception of *strawberry*, were bisyllabic.

This initial list of 116 compounds was presented to 91 undergraduate students who were asked to rate each compound in term of the extent to which its meaning was predictable from the meanings of its parts. A four-point rating scale was employed in which the alternatives ranged from 'very predictable' to 'very unpredictable.'

In a second task, the 91 participants were presented with the same list of 116 compounds with one of the constituents underlined. In this task, the participants were asked to focus on the transparency of the constituent rather than on the transparency of the compound as a whole. Again, a four-point scale was employed and participants rated the extent to which the constituent retained its individual meaning in the whole word on a four-point scale with alternatives ranging from 'retains all of its meaning in the whole word' to 'loses all of its meaning in the whole word.'

The results of this rating study allowed us to select a set of 40 TT, OT, TO, and OO compounds (10 in each group) such that the TT compounds showed the highest overall transparency scores in Task 1 and the greatest balance between first-constituent and second-constituent transparency ratings in Task 2. The most balanced compounds with the lowest overall transparency ratings were selected as OO compounds and, finally, the sets of TO and OT stimuli were created from the group of compounds with mid-range overall transparency and the greatest imbalance in transparency ratings for first and second constituents. These optimization procedures were designed to ensure that all stimuli fell as clearly as possible into one of the four stimulus categories and resulted in the classification of forty core compound stimuli listed in Table 1. Table 1 also shows the frequencies of each compound per million as listed in the CELEX spoken and written English corpus.

The optimization procedure, however, may have resulted in a compromise of control over other stimulus variables. For example, although the initial list of 116 compounds was balanced for frequency, the 91 undergraduate participants who rated the potential stimuli showed a tendency to select the more frequent compounds as completely transparent (TT).

Differences arising from semantic factors across the four stimulus categories that would make some stimuli more salient than others were investigated in a pencil and paper experiment/pretest with 84 participants. In the experiment, participants were

Table 1
The core compound stimuli divided by the semantic transparency of their constituents into four groups: Transparency–Transparent (TT), Opaque–Transparent (TO), Transparent–Opaque (TO), and Opaque–Opaque (OO) and rated for frequency

	TT	Frequency	OT	Frequency	TO	Frequency	OO	Frequency
1.	Bedroom	56	Chopstick	0	Cardshark	NL	Deadline	3
2.	Coalmine	0	Crowbar	1	Doughnut	1	Dingbat	NL
3.	Daylight	16	Dashboard	2	Heatwave	0	Fleabag	0
4.	Doorbell	2	Godchild	0	Jailbird	0	Hallmark	2
5.	Farmyard	2	Jackknife	NL	Oddball	0	Hogwash	0
6.	Fencepost	NL	Nickname	4	Shoehorn	0	Humbug	2
7.	Paintbrush	1	Pothole	0	Slowpoke	0	Ragtime	1
8.	Rosebud	1	Shortcake	0	Sourpuss	0	Rugrat	NL
9.	Sailboat	0	Strawberry	3	Spoilsport	0	Stalemate	1
10.	Schoolboy	6	Sunfish	0	Staircase	0	Windfall	2

NL = not listed.

presented with the list of 40 compounds on a sheet of paper. They were allowed three minutes to read the list and were then presented with an arithmetic distracter task. Finally, following the distracter task, participants were presented with a sheet of paper that contained the eighty constituent morphemes of the original compound list. These constituents were arranged in random order and participants were instructed to circle those words that were present in the original compound list. Their responses were analyzed in a two-way repeated-measures ANOVA that revealed a significant effect of position, $F(1,83) = 19.45$, $p < .001$, such that initial morphemes were better identified than final morphemes and a significant effect of compound type, $F(2,249) = 2.94$, $p < .05$. This effect was localized such that constituents of the OO compounds were identified more frequently than constituents of the other three compound groups, $F(1,83) = 8.56$, $p < .01$.

The results of pretesting, therefore, led us to the conclusion that OO stimuli were more salient than other types, and that initial constituents were more salient than final constituents. This, along, with the frequency asymmetry between TT compounds and the other three types, requires that we be cautious in the interpretation of results based on experiments in which the stimuli have not been used as their own controls. Thus, both experiments described below employ within-participants and within-items repeated-measures designs.

4. Experiment 1: Normal and broken

One way to conceptualize morphological decomposition is simply as a separation of a compound into its constituents (e.g., *hogwash* → *hog wash*). If that is the case, it would be reasonable to assume that compounds that are actually decomposed into their constituents would be less affected by an alteration of the stimulus into two actual words than those that are not decomposed. Additionally, if semantic transparency plays a role in determining whether a word is decomposed, it would be predicted that recognition time for a word such as *hogwash* with spaces between the morphemes would be greater than response times to a transparent word such as *carwash* under the same presentation conditions. This prediction was tested in Experiment 1.

4.1. Method

4.1.1. Participants

Fifty undergraduate students in linguistics participated as volunteers in the experiment. All participants were native speakers of English.

4.1.2. Procedure

Participants were tested individually on a Power Macintosh running Psyscope 1.02. using the Macintosh millisecond timer. At the outset of the experiment, participants were told that they would see single words presented in the center of the computer screen. They were instructed to press the 'yes key' if they had ever seen the word before and to press the 'no key' if they had never seen the word before. Participants were also instructed to ignore spaces in words if these were to occur.

Participants performed 7 practice trials after which the main experiment was run in a single block of 160 trials. The participant initiated each trial by clicking the mouse button with their nonpreferred hand. The stimulus appeared on the screen 500 milliseconds after the mouse click and remained on the screen until either the 'yes' or 'no' key was pressed with the preferred hand. Each participant was presented with each of the compound stimuli twice-once in normal typeface and font (Chicago 24 pt) and once in the same font and size but with two spaces between the constituent morphemes. This accounted for 80 of the 160 trials. The additional 80 trials were filler trials in which 40 words containing real and nonsense roots (e.g. *blimsap*) and 40 nonexisting compounds (e.g., *mouseplot*). Half of the filler items were presented with spaces between constituents and half were presented in normal format.

4.2. Results

Data from 49 of the 50 participants were analyzed in terms of accuracy and latency of correct responses. The one deleted case showed both an RT and accuracy score more than three standard deviations away from the mean.

4.2.1. Response accuracy

The response accuracy results are displayed in Table 2. These results indicate a slight decrease in accuracy across all compound types with the TT compounds showing the lowest apparent cost associated with the presence of spaces between the morphemes. However, the absence of an interaction effect as discussed below suggests that individual compound types cannot be described as differentially sensitive to the presence of an intermorphemic gap. In the items analysis, summing over participants, the data were analyzed in a two-factor ANOVA with compound type as a between-items factor and presentation type as a repeated measure. The ANOVA showed a marginally significant effect of compound type, $F(3,36) = 2.83$, $p < .052$, and a significant effect of presentation type, $F(1,36) = 69.01$, $p = .0001$. The effect of split cost (the interaction of the compound type and presentation type factors) was not significant, $F(3,36) = .88$, $p = .45$. The participants analysis also yielded a significant effect of compound type, $F(3,144) = 9.45$, $p < .0001$ and presentation type, $F(1,48) = 6.6$, $p = .013$ but no significant interaction effect, $F(3,144) = .962$, $p = .41$.

4.2.2. Response times

Response times to correct responses were analyzed in items and participants ANOVAs. Data points below 300 ms were excluded from the database (3 trials of 5000 in the dataset) and RTs above 1500 ms were recoded to 1500 ms. In Table 3, the response time means and standard deviations for each of the experimental conditions are presented and the overall pattern of results is presented graphically in Fig. 1.

In the participants analysis (summing over individual stimuli), a two-way ANOVA with repeated measures on both factors revealed a significant effect of compound type, $F(3,144) = 6.23$, $p = .0005$, and a significant effect of presentation condition, $F(1,48) = 14.7$, $p = .0004$. The interaction of the two factors was not significant, $F(3,144) = 1.14$, $p = .33$. In the items analyses, there was a marginally significant effect of the between-items factor, compound type, $F(3,36) = 2.4$,

Table 2
Lexical decision response accuracy (%) for compounds presented in normal form or with spaces between constituent morphemes (split)

Type	Normal	Split	Normal minus split
TT	99%	97%	2%
OT	98%	91%	7%
TO	98%	92%	6%
OO	95%	91%	4%

Table 3
Means and standard deviations of response times in milliseconds for compounds presented in normal form or with spaces between constituent morphemes (split)

Type	Normal		Split		Split cost (S–N)
	Mean	*SD*	Mean	*SD*	
TT	691	173	750	227	59
OT	698	189	781	237	83
TO	746	204	783	236	37
OO	740	200	784	239	44

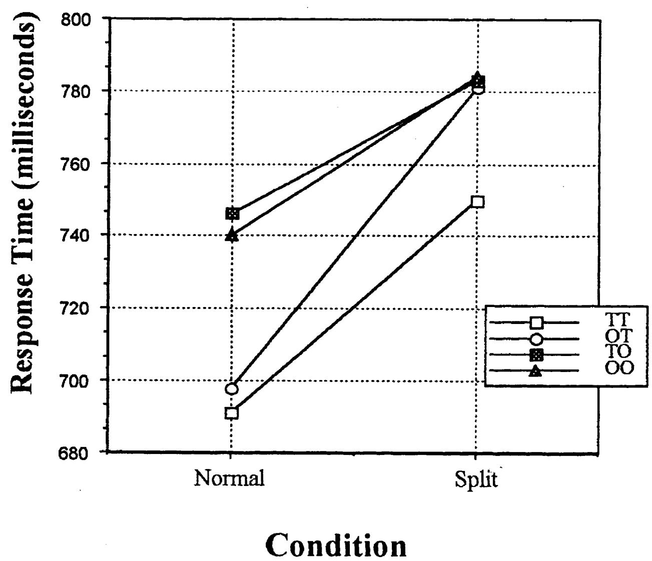

Fig. 1. Response patterns for compounds presented in normal and split form.

$p = .08$, and a significant effect of the within-items factor, presentation type, $F(1,36) = 27.9$, $p < .0001$.

As can be seen in Table 3 and Fig. 1, response times for the normal presentation condition show an RT difference between compounds with transparent heads (TT and OT) and compounds with opaque heads (TO and OO). This difference was significant in a planned comparison, $F(1,144) = 12.8$, $p = .0005$ as was the clustering in the split condition in which RTs for TT compounds were lower than those for the compounds with opaque elements, $F(1,144) = 4.33$, $p = .03$.

4.2.3. The repetition effect

As we have stated above, each participant in the experiment saw each compound twice, once in the normal condition and once in the broken condition. The order of stimulus presentation was rerandomized for each participant. This design allowed us to investigate the effect of repetition for each class of stimuli. In other words, we were able to examine the extent to which response times to the first presentations of stimuli differed from their response times when they were seen for the second time. In Table 4, we present the response time data broken down by first and second appearance.

As can be seen in Table 4, there was an overall repetition effect for both the normal and split conditions, $F_{\text{subj}}(1,48) = 31.8$, $p < .0001$; $F_{\text{items}}(1,38) = 127.9$, $p < .0001$. Moreover, an interesting pattern emerges which again distinguishes the

Table 4
Response times to the first and second presentations of stimuli

Type	Normal		Split	
	1st	2nd	1st	2nd
TT	728	654	761	739
OT	723	673	781	781
TO	790	702	817	749
OO	769	711	819	749
Average	752	685	794	754

Note. The second presentation of the Normal stimulus was always preceded by a Split presentation with a random number of other stimuli intervening. For the second presentation of Split stimuli the reverse was the case: it was always preceded by a Split presentation of the same stimulus with a random number of items intervening.

Table 5
Repetition effects

Type	Split Cost	
	1st	2nd
TT	33	11
OT	58	58
TO	27	−41
OO	50	−20

Note. The split costs are calculated as the RT of the Split conditions minus the RT of the first presentation of the intact stimulus in both cases. The rightmost column shows the difference between the RTs for the first and second split conditions.

compounds with opaque heads (TO and OO) from those with transparent heads (TT and OT). Specifically, the TO and OO compounds showed a much stronger repetition effect in the split condition than the TT and OT compounds. This effect is shown in Table 5. As can be seen in this table, the TO and OO compounds are significantly faster in the second split presentation (indicated by a negative split cost), $F_{\text{subj}}(1,48) = 7.5$, $p = .009$; $F_{\text{items}}(1,38) = 6.7$, $p < .01$. Proportionally, they are enjoying a greater benefit of prior intact presentation in comparison to the TT and OT compounds.

4.3. Discussion

The four dominant results from Experiment 1 are (a) all compound types take longer to recognize when they are represented in split form; (b) TO and OO compounds take longer to recognize than OT and TT compounds; (c) the compounds with opaque elements pattern together in the overall split condition; (d) the TT and OT compounds are less affected than TO and OO compounds by prior presentation as intact stimuli.

The result that TT and OT compounds are classified more quickly supports the view that morphological headedness may play a role in the processing of compounds. TO and OO compounds are those in which the morphological head of the construction is opaque. This suggests that whether the compound can be interpreted as *a type of X*, where *X* is the rightmost element, affects the manner in which it is represented in the lexicon and perhaps the manner in which the parallel activation of its constituents can facilitate or conflict with its recognition as a whole. The fact that the OT and TT compounds patterned together in simple lexical decision latencies is noteworthy for two additional reasons: First, the OT compounds are those that are the most comparable to those employed by Sandra (1990) and second, if TT were alone in this privileged position, we would be concerned that it was perhaps their higher frequency that generated the result.

The second main result from Experiment 1 was that all compounds were classified more slowly as words when spaces were present between the morphemes. We interpret this to support the view that all compounds—even the most transparent—have their own representations as recognition units in lexical processing. If this were not the case, compounds would be equally recognizable in single-word, split-word and possibly hyphenated form because the only factor influencing recognition would be whether the constituent morphemes were activated together and in the correct order.

This brings us to the last major finding. The fact that TO and OO compounds show a greater repetition effect suggests to us that, in the context of this experiment (one in which all real words were compounds), the compound nature of these items was highlighted in the first presentation, resulting in a relatively lowered RT in the second Split Condition. Thus, all other things being equal, the presence of an opaque head may make a stimulus less compound-like. This point of view leads to a direct prediction for the constituent priming experiment reported below. If TO and OO are indeed less compound-like, they should show smaller constituent priming effects in general and much smaller head priming effects in particular.

5. Experiment 2: constituent priming

In this experiment, we employed a constituent priming paradigm to investigate whether prior activation of a compound's constituents facilitates recognition of the whole word. As is described below, this experimental paradigm involves a brief presentation of a compound constituent immediately followed by presentation of the compound as a whole. Thus, the paradigm can be seen as an enhancement of what would routinely occur in word recognition under the morpheme decomposition hypothesis.

5.1. Method

5.1.1. Participants

Eighty-seven undergraduate university students participated as volunteers in the experiment. All participants were native speakers of English and none had participated in Experiment 1.

5.1.2. Procedure

The experiment employed a priming paradigm in which both prime and target stimuli were presented on the screen of a microcomputer and lexical decision latency and accuracy served as dependent variables.

In each trial, the participant first saw a fixation point presented in the center of the screen for 500 ms. The screen then went blank for 250 ms. after which a monomorphemic word (the prime) was presented for 150 ms. in 24 point font. At the end of the 150 ms presentation, the prime was replaced on the screen by a compound word (the target). This target stimulus remained on the screen until the participant made a lexical decision by pressing either a key labeled "yes" or a key labeled "no." Thus each trial in the experiment consisted of the presentation of a prime–target pair and single lexical decision response to the target stimulus. Each participant was presented with 140 prime–target pairs in a single block of trials.

Table 6
Prime–target pairs for TT, TO, OT, OO, and nonsense compounds

Target		Prime		
Cat	Example	Neutral	Initial	Final
TT	(*car-wash*)	pen	car	wash
OT	(*strawberry*)	bed	straw	berry
TO	(*jailbird*)	table	jail	bird
OO	(*hogwash*)	tree	hog	wash
Nons	(*beargap*)	book	bear	gap

The core stimuli in the experiment were the same forty compounds used in Experiments 1 and 2. Each compound was seen twice by a participant, once preceded by a neutral prime (e.g., *pen–car-wash*) and once either preceded by an initial constituent prime (e.g., *car–car-wash*) or a final constituent prime (e.g. *wash–car-wash*). In this way, the 40 core stimuli accounted for 80 of the 140 presentation trials. The remaining 60 trials were considered to be filler trials designed to generate "no" responses in the lexical decision task. These trials were structurally identical to the core trials and involved the presentation of a monomorphemic prime and a compound target. In these cases, however, the compound target was a nonexisting word composed of two real morphemes (e.g., *beargap*). The order of prime–target was rerandomized for each participant in the experiment. Table 6 summarizes categories of prime–target target pairs discussed above and presents the framework for the two-way repeated-measures ANOVA that was performed on lexical decision response times and accuracy.

5.2. Results

As in Experiment 1, response times greater than 1500 ms were recoded to 1500 ms and the data were analyzed in a two-way within participants ANOVA. In Fig. 2, RTs are shown for the four compound types in the three priming conditions. The error rate was less than 3% in all conditions and was not analyzed.

The results showed significant main effects of both compound type and prime type in both the items and participant analyses, F_{subj} for compound type $(3, 258) = 37.8$, $p < .0001$; F_{items} for compound type $(3, 36) = 6.7$, $p = .001$; F_{subj} for prime type $(2, 172) = 35.4$, $p < .0001$; F_{items} for prime type $(2, 72) = 69.3$, $p < .0001$. No interaction was found between compound type and prime type $F_{\text{subj}}(6, 516) = 1.1$, $p = 0.36$; $F_{\text{items}}(6, 72) = 1.6$, $p = .14$. As can be seen in Fig. 2, response times were greatest for the OO compounds, followed by the TO compounds. The OT and TT compounds patterned together in all priming conditions.

The overall response time results can be summarized in the following manner: All compounds can be facilitated by previous presentation of their constituents. The compounds with opaque morphological heads (OO and TO) were more difficult to process than compounds with transparent heads (OT and TT). OT compounds showed RT patterns that were nondistinct from TT patterns despite the difference in lexical frequency discussed above. The OO and TO compounds did not show the decreased priming effects we have predicted.

5.2.1. Repetition effects

As in Experiment 1, participants saw each compound in the experiment twice. In this case, one presentation was always unprimed and the other was either primed by its first constituent or primed by its second constituent. The order of presentation

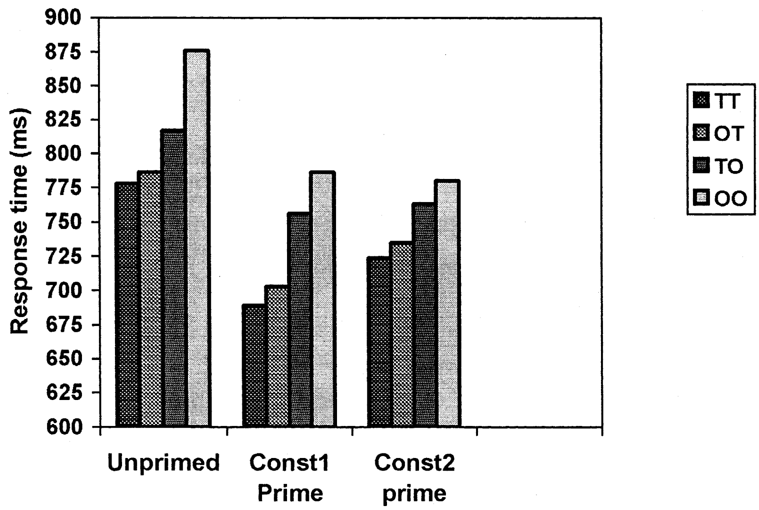

Fig. 2. Lexical decision response times to compounds proceeded by neutral, first constituent, and final constituent monomorphemic primes (based on items RTs).

Table 7
Response times in milliseconds and standard deviations (in brackets) for the first and second presentations of each stimulus type

	TT	OT	TO	OO
First presentation				
Unprimed	810 (65)	850 (51)	877 (71)	935 (55)
Primed by constituent 1	739 (87)	747 (94)	826 (72)	854 (60)
Primed by constituent 2	765 (52)	778 (86)	842 (79)	840 (87)
Second presentation				
Unprimed	748 (30)	722 (47)	758 (50)	817 (91)
Primed by constituent 1	640 (60)	659 (30)	687 (69)	719 (76)
Primed by constituent 2	684 (75)	692 (56)	684 (48)	721 (42)

was re-randomized for each participant. Thus, as in Experiment 1, we were in a position to investigate the extent to which the four categories of compounds responded differently to the effect of repetition (see Table 7). As we observed in Experiment 1, the TO and OO compounds seemed to benefit from repetition in a manner that the compounds with transparent heads (TT and OT) do not. Fig. 3 shows the extent to which response times in the primed conditions were improved by prior presentation of the unprimed compound. As can be seen in this figure, there is a difference among the four compound types, $F_{\text{subj}}(3, 258) = 2.86$, $p = .04$; $F_{\text{items}}(3, 36) = 3.09$, $p = .03$. Specifically, primed response time differences were significantly greater for the TO and OO on second presentation. This finding parallels that of Experiment 1 and suggests that in the context of this stimulus list and this task, compounds with opaque heads are rendered more compound-like following an initial presentation.

6. General discussion

Our point of departure in this study was the assumption that semantic transparency is related in a nontrivial way to the manner in which multimorphemic words

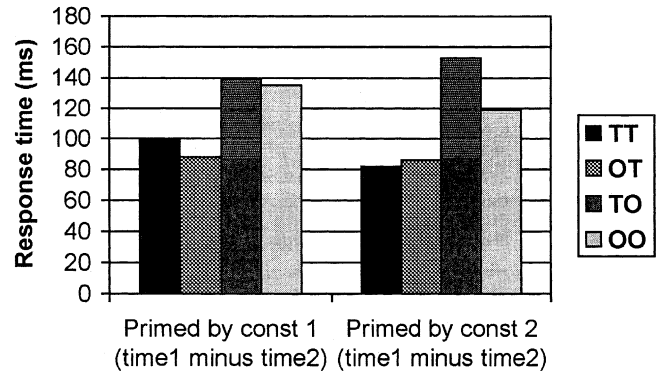

Fig. 3. Response time improvement in the primed conditions. The left side of the graph shows first constituent (const1) primed RTs for the first presentation (time1) minus the first constituent primed RTs for the second presentation (time2). The right side of the graph shows the same first vs second presentation differences for compounds primed by their second constituents (const2).

are represented and processed. With respect to the particular question of morphological decomposition in compound recognition, previous studies such as those by Marslen-Wilson et al. (1994), Sandra (1990), and Zwitserlood (1994) had pointed very strongly to the view that morphologically opaque words are resistant to activation through prelexical decomposition.

But what characterizes a morphologically opaque word? In this investigation, we took the approach that morphological opacity may be described as the manner in which a morpheme's semantic characteristics in a multimorphemic word correspond to its semantic characteristics as a free-standing lexical item. This approach leads naturally to the classification of bimorphemic compounds in terms of the two-way grid used in our experiments and to the question that we now address: Does the morphemic approach to the concept of transparency provide insight into the representation and processing of compound words?

We suggest that it does. In both the experiments we report, the data show patterns that could only be revealed through a deconstructed approach to semantic transparency. Of these patterns, three stand out as most important to our understanding of the role that semantic transparency plays in the representation and processing of English compounds. These are:

(1) Both initial and final constituents prime all compound types.
(2) Compounds with opaque heads take longer to process.
(3) Response patterns for compounds with opaque head change with repetition.

Turning to the first of the three findings, we note that we did not find that only morphological heads prime or that only transparent constituents show priming effects. Rather, found that both initial and final constituents primed full compound forms of all four types. To what extent, then, do these results contradict those of Sandra (1990)? If we assume that English morphological structure and processing are comparable to those of Dutch, Sandra's results would predict that we find no priming effects for OT, TO, and OO compounds. The reasoning here is that OT compounds are the most transparent of these stimuli because they maintain a transparent head. Because these were the opaque compounds with which Sandra found no priming effects, we should have seen no effect with any compound containing an opaque element. However, we did find priming effects throughout. We suggest that the source of this discrepancy lies in the differences between the experimental paradigms used in the two studies. The compound splitting technique and the constituent priming technique that we employed targeted the activation component of the word recognition process. The semantic priming technique, on the other hand, targets lines of association within the lexicon. So, for example, *wash* may facilitate the recognition of *hogwash* because it primes the actual form of a constituent as a unit of recognition. An associate of *wash*, say *soap*, would not directly affect such a unit of recognition. Thus, we must conclude that at the level of processing we targeted, constituent activation *does* occur. This does not preclude, however, the possibility that opaque multimorphemic words may not show constituent activation at other levels of processing. We take this to be further evidence that morphological processing phenomena are best approached through a variety of experimental paradigms.

Our second main result in both Experiments 1 and 2, was an effect of morphological headedness. Throughout, the latency data showed that TT and OT compounds patterned together and were easier to process than compounds with opaque heads. We suggest that one reason for this is the composition of our stimulus list. Both experiments presented participants with a large number of compounds and may have induced them to process stimuli in what might be described as 'compound mode.' It is precisely in this mode that TO and OO compounds are outliers. They cannot be understood as 'a type of *X*,' where *X* is the morphological head and rightmost constituent. Support for this line of reasoning is to found in a recent study by Jarema, Busson, Nikolova, Tsapkini, and Libben (1999), which used a similar type of stimulus set for French, a language in which the head of a compound can be in both initial and final position. Jarema et al. (1999) found significant differences in response latencies and priming effects for right-headed and left-headed OT compounds, indicating that the role of headedness that is independent of position.

The third main finding across the two experiments concerns the sensitivity of TO and OO compounds to the effect of repetition. Our account of this effect builds on the considerations in the paragraph above. If indeed, TO and OO English compound are less compound-like, and if the composition of the stimulus list plays a key role in this experiment, then it is possible that the initial presentation of these stimuli makes their compound structure more salient to participants. In Experiment 1, we found that, whereas the TT and OT compounds showed very little difference between the RTs of the first and second split presentations (22 and 0 ms, respectively), the TO and OO compounds showed RT differences of 68 and 70 ms, respectively. Similarly, in Experiment 2, the priming effects were substantially higher for TO and OO compounds on second presentation. In addition to what these patterns reveal about the role of headedness in compounding, they point to the nonuniform role that repetition may play across stimulus types in lexical decision experiments in general.

In conclusion, then, our findings suggest that semantic transparency plays a critical role in the processing of compounds. The semantic transparency of a compound as a whole is related to the transparency of its individual morphemes, and whether or not they are in the morphological head or nonhead position. If semantic transparency were simply a property of a whole word, then OO, TO, and OT should have been indistinguishable (which is not what occurred). If it were only the number of opaque elements that influences constituent priming results, then TO and OT compounds should have patterned together (which they did not). Thus, the results force us to a complex view in which we must consider the opacity of individual morphemes in a construction, their position in the string, and their morphological and semantic roles in the meaning of the word. Finally, the role that these factors play can be affected by the course of the experiment itself, resulting in a differential repetition effect for particular classes of stimuli.

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