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Is a *Step* through the *Door* a Way to Take a *Doorstep*? A Psycholinguistic Study on Polish Compound Words

Abstract: The present study concentrates on the organization of the mental lexicon with regard to semantic transparency in the representation of Polish compounds. Its aim was to test current approaches to the processing of morphologically complex words in a lexical decision experiment with the use of visually presented Polish compound and simple words. The existing psycholinguistic approaches centre around the same question: are complex words parsed into their constituent parts or are they stored as full-word representations in the human mental lexicon? I referred to five widely acknowledged models of morphological processing to account for the outcomes of the present study. The data reveal that: (i) transparent compounds primed by words semantically related to the heads of these transparent compounds elicited faster response times than opaque compounds within the same condition; and (ii) priming speeds up the processing for both transparent and opaque compounds. The results indicate that the processing of Polish compound words is influenced by semantic transparency and that both transparent and opaque compounds are decomposed into their constituents prior to lexical access.

Keywords: mental lexicon, compounds, semantic transparency, lexical decision, masked priming, native speakers, morphological processing

1. Introduction: morphological processing

Over the last five decades, a rising number of studies have been devoted to the problem of morphological processing in the visual recognition of complex words (the products of inflection, derivation and compounding). On the way from encountering the word to arriving at its meaning, are words such as *snowman*, *eye-tooth*, and *jailbird* parsed into their components (and perhaps activated after the reassembly stage), or are they stored as whole-word forms? The above issue often boils down to the issue of the interplay between decomposition and storage. This debate has been the point of scientific interest for over 50 years and still has not been resolved (Amenta & Crepaldi 2012). There are many factors influencing the processing of complex words, such as word frequency, semantic transparency, the type of language examined, the sort of morphological complexity (inflection, derivation or compounding), or the type of input procedure (visual vs. auditory). Given that this study employs a visual input modality presented to native speakers, the present article focuses on models which are compatible with this type of input.

Another important question concerning the processing of complex words is whether all those words follow an identical route, or whether there are different possibilities depending on the factors listed above and possibly some not yet identified. The studies which have so far focused on the processing of morphologically complex words typically involved derived or inflected words. The studies on compound words are seriously under-represented.

Applying the same methods and models for testing morphological processing while studying the products of derivation, inflection and compounding stands as one of the major factors which causes the inconsistency between the results. This is so because the process of compound formation engages joining two or more independent roots, while the process of affixation or derivation engages joining one or more affixes to only one independent root. Therefore, Libben (2013) suggests that affixes can be stored in the mental lexicon in the form of a list because they constitute a finite set of items. Such a list is then employed along with combinatorial algorithms (e.g., adding the affix *-ous* to a noun creates an adjective, or adding the affix *-er* to a positive form of an adjective creates a comparative form of the adjective). A similar strategy would clearly be impossible in the case of compounding because compounds can be formed out of virtually any open-class words. A similar list of possible roots that could be employed in compound morphological processing is unlikely to exist, which, in turn, indicates that the products of derivation and inflection are unlike products of compounding.

The study has been planned in a way which should provide us with answers to the following research questions: (i) How does the internal structure of compound words influence their processing? (ii) Are response times for semantically transparent compounds faster than those for opaque ones? Do they follow the same processing route?

1.1. Approaches to the processing of complex words

Even though a substantial body of evidence offers unambiguous models of morphological processing, virtually all of these models have been based on the results from testing derivational or inflectional morphology. Therefore, accounting for the processing of compounds using some of these models remains doubtful (Libben 1998). I have selected five extensively used models, three of which have been based on inflectional and/or derivational morphology and two based on the study of compound processing by El-Bialy, Gagné and Spalding (2013). All these models are based on the juxtaposition of the procedures that are proposed to explain the processing of compounds: the parsing model (i.e., decomposition), the listing model (i.e., storage), and dual-route approaches which rely on the juxtaposition of the parsing and the listing models.

The first of these accounts is Butterworth's (1983) full listing-model which asserts that all complex words are stored in the mental lexicon as full forms. The listing model procedure engages activation of the whole word (i.e., its complete orthographic and/or phonological form) that is stored in the human mental lexicon. The mechanisms involved in the listing model are fast and associative. Butterworth regards the mental lexicon as the net of words which are connected to one another by associative links. This is one of the most radical models of morphological processing because it suggests that both transparent and opaque compounds follow the same route, i.e., listing.

The second account is Taft's (2004) model, which claims that all complex words initially follow the parsing route and, unless the meaning is found, the words can be accessed via listing. This model suggests that the representations on the lemma level (i.e., the representation of a specific meaning but without the sounds attached to it) connect functional properties (i.e., semantic and syntactic properties) and form (i.e., orthographic and phonological properties) and contain both free and bound morphemes: free morphemes are the ones that can stand in isolation as an independent word, while bound morphemes may not. According to this framework, transparent complex words (such as *mending* or *seeming*) do not have their own lemmas because the functional properties of the words can be inferred purely from their components (i.e., *mend-* and *-ing* as well as *seem-* and *-ing*). Opaque complex words (such as *feathery*), on the other hand, are associated with functional properties that cannot be determined entirely from their components (i.e., the stem *feather-* and the suffix *-y* as *feathery* attributes to "lightness" or "softness", not "feather-like shape"). Thus, opaque words require their own lemmas in order to connect the form with its semantics. However, the presence of the lemma of a specific opaque word does not necessarily entail the presence of a full word representation on the form level (e.g., the lemma of *feathery* may still be activated through the representation of its components, i.e., *feather-* and *-y*). According to Taft (2004), the more transparent and frequent the word is, the more probable it becomes to follow the decomposition route. His approach supports the view that semantic transparency[1] influences the processing of compound words. On the other hand, Butterworth's (1983) model contradicts this view because he claims that

[1] Semantic transparency is the degree to which the meaning of whole compound can be inferred from the meanings of its constituents, e.g., *snowball* is semantically transparent because it means 'a ball made of snow', while *greenhorn* is not because it does not mean "a horn which is green" but it denotes "an unexperienced person".

all compounds are memorised as chunks of language and are not undergone the process of decomposition.

The third approach — the supralexical model — was developed by Giraudo and Grainger (2000) on the basis of four lexical decision experiments[2] concerning the processing of inflectional morphology in French. Its crucial assumption is that any complex word is retrieved as a whole-word form first, and morphological effects are available only afterwards. For instance, the stimulus *growing* activates the full form representation growing, which in turn activates the morphemic representations *grow-* and *-ing* that already possess their own semantic and syntactic information. In other words, the activation of the meaning of a full-form representation occurs prior to the activation of its individual components. Although the supralexical model gained a great amount of interest, it is slowly being rejected over time as new evidence speaks against its assumptions (e.g., Bronk, Zwitserlood, Bölte 2013). One possible problem with the supralexical model is the fact that subjects are sensitive to the morphemes of complex non-words (e.g., the morphemes of *invive*, where *in-* is an inappropriate prefix attached to the bound morpheme *-vive*, found in *revive* or *survive*: Taft 1994).

The other two approaches have been based on Taft's (2004) model. They both assume that compound processing is affected by the degree of semantic transparency but in a slightly different manner. The first model, the conjunctive activation approach (CAA), is so called because "conjunctive" refers to the sort of connection between the constituents (Libben 1998). What emerges from this approach is that transparent compounds are processed faster than opaque compounds and that the transparency of opaque compounds does not influence the processing (there is no negative priming effect[3]). The second approach, the meaning computation approach (MCA), claims that components' semantics is activated regardless of compound semantic transparency (Ji et al. 2011). Yet the processing costs are higher for opaque compounds than for transparent compounds because the composed representation in the case of opaque compounds contradicts the traditional representation[4] and, therefore, needs to be rejected to the benefit of the meaning which is already lexicalized and stored in the mental lexicon. Thus, the processing of transparent compounds takes less time than the processing of opaque compounds but the opacity has a negative impact on the processing (there is a negative priming effect). The additional entailment from MCA is that there should be a difference in

[2] The lexical decision experiment involves measuring response times for classifying the stimuli as words or non-words.

[3] Negative priming effect occurs when the processing is slowed down.

[4] The traditional / standard representation is the one that exists in the real world (or at least in fiction), e.g., when we process *strawberry* the traditional interpretation is 'a type of fruit', while the non-traditional one is 'a berry with straws inside' or 'a berry speared with a straw' etc. According to MCA, when an opaque compound is decomposed, such non-traditional interpretations may occur but they are pushed out by the traditional ones.

the processing of lexicalized and novel opaque compounds and such a difference should not occur for lexicalized and novel transparent compounds.

To briefly recapitulate, the Taft's model does not assume that there is either no or negative priming for opaque compounds (the approach only suggests that transparent compounds are processed faster than opaque ones). CAA and MCA are more specific because they already imply what type of priming effect may be expected.

1.2. Factors influencing the processing of compounds

A substantial body of evidence from the processing of compounds comes from studies investigating a single language (Libben & Jarema 2002). There have been nine languages tested so far: Dutch (Sandra 1990; Zwitserlood 1994), German (Bronk et al. 2013), English (Libben 1998; Fiorentino & Fund-Reznicek 2009), Greek (Dalalakis 1999), Finnish (Mäkisalo et al. 1999), Italian (Delazer & Semenza 1998; Mondini et al. 2004; Marelli & Luzzatti 2012), Japanese (Kudo 1992), Chinese (Zhou & Marslen-Wilson 1994) and Hebrew (Berman & Clark 1989). Slavic single-language studies are seriously under-represented (Libben 2013). There exist only five cross-linguistic studies and they investigated the following languages: Greek vs. Polish (Kehayia et al. 1999), German vs. Greek vs. Polish (Baayen et al. 2002), Dutch vs. English (Schreuder et al. 1998; de Jong et al. 2002), French vs. Bulgarian (Jarema et al. 1999). There is one more study conducted on bilingual speakers of French and English (Nicoladis 2002). The majority of the data concern Germanic and Romance languages. Cross-linguistic studies, though rare, are particularly important because results acquired from them can shed some light on the issue of compound processing from a broader, more general perspective.

It is worthy of attention that providing evidence that is distributed along the poor-to-rich continuum of morphological complexity allows us to discover universal principles. This is because compound words in different languages seem to be processed in a different way. Thus, it is important to remark that existing theories and models may be verified with data obtained from testing further languages. Also, the methodology of the experiments is gradually changing and, even languages which have been thus far explored, require more precise observation. The present study tests Polish compounds that vary in terms of semantic transparency and that are constant in terms of word frequency. These factors are known to significantly influence the processing of compounds but they have not been tested in Polish yet.

Semantic transparency is defined by the relationship between the meaning of the constituents and the meaning of the entire compound. For transparent compounds, the compound meaning is the sum of the constituents' literal meanings (e.g., *rainstorm* is 'a storm with a lot of rain'). Opaque compounds, on the other hand, display no relation between the meaning of the whole form and the meanings of its components (e.g., *humbug* is not '*a bug that hums' but 'a dishonest act'). Sandra (1990) in his English study confronted transparent compounds with opaque compounds and observed that the positive priming effect occurred only for the transparent ones, which indicates that there are differences in compound processing. He accounted for the results arguing that transparent compounds are parsed and the opaque ones listed in the mental lexicon. Libben (1998), however, discovered semantic priming for both transparent and opaque compounds, stating that Sandra's experiment was designed so that it activated the associations within the mental lexicon, not during lexical identification.

Word frequency determines the speed at which certain word is activated (see Andrews 1986). The frequency of occurrence is then the feature of word form, which, in turn points to the fact that frequent words are accessed faster than infrequent ones. As for the family size effects, contradictory results have been obtained in the literature. Morphological family is the cumulative number of all types of one form used in a language (e.g., of the word go would be *goes*, *going*, *gone*, *went*, *goner* etc.). The effect of a morphological family has been reported to influence word identification. However, morphological family frequency (the total sum of the frequencies of the morphological family) has been reported not to influence word identification (Schreuder & Baayen 1995). In light of the discrepancy between the results, de Jong et al. (2002) tested whether family size and family frequency affect reaction times of compound processing. They obtained results which suggested that family size effects significantly influence the processing, while family frequency effects do not. They additionally concluded that there is another factor that influences the processing of compounds to a higher degree than family size effect: the position of family frequency (the position the component takes within a compound, i.e., whether the component and its family are more frequently used as the non-head or as the head of a compound). The general conclusion that can be deduced from the studies on frequency effects is that the processing of compounds is dependent on morphological structure, that the process of decomposition happens peripherally (at the level of form representation), and that compound words behave differently than simple (i.e., simplex) words and than their components.

The problem of the interplay between storage and computation has gained a great deal of interest in the psycholinguistic literature investigating the processing of compounds. Even though the results of these studies are somewhat contradictory (Libben 1998), the conclusions point to the fact that opaque compounds are parsed for English (Frisson et al. 2008; El-Bialy et al. 2013), Dutch (Zwitserlood 1994), French, Bulgarian (Kehayia et al. 1999), Greek, Polish (Jarema et al. 1999) and Finnish (Pollatsek & Hyöna 2005). Thus, to further test the role of semantic transparency, the current study used the masked semantic priming technique. Masked semantic priming has become a common technique in the studies on compound visual recognition. Masked priming produces morphological effects during compound identification (e.g., Fiorentino & Fund-Reznicek 2009). These effects are detachable from semantic and formal overlap effects that are believed to affect processing in some other techniques (e.g., standard semantic priming). As the outcomes are often mixed, the masked semantic priming technique has developed into a critical testing paradigm when it comes to the interplay between storage and computation of compound words.

In the studies of El-Bialy et al. (2013) and Fiorentino and Fund-Reznicek (2009), the semantic priming technique was used to test the processing of English compound words. The primes used in their studies were compound words and the target items were the non-head components, e.g., *eyesight* — *EYE*. The research has a number of limitations. Firstly, the prime words may not only activate semantics of the target words, but some additional information as well. This information, coming from a phonemic and/or orthographic overlap, might be responsible for the facilitation of an access to the representations of the target words. Additionally, not enough attention was given to the assignment of the semantic transparency feature to the compounds they used as they used their own intuition in deciding whether a given compound is transparent or opaque. Thus, taking the aforementioned issues into consideration, I ensured that: (i) the prime words in my study are separate from the possible phonemic or orthographic overlap with respect to the compounds they primed, and (ii) the meanings of compounds labelled transparent are activated via the meanings of their constituents and the meanings of compounds labelled opaque are not — to test this I conducted a rating study in which the participants judged the extent to which the components are semantically related to the entire compound (see section 2 for more details).

On the basis of the assumption that compound processing is dependent on word frequency and semantic transparency, I can establish the degree to which the internal structure of morphologically complex words affects the route selected for different types of compounds.

2. Experiment: Masked priming of head / word-final position

In my study, current approaches to the processing of morphologically complex words are tested in a lexical decision experiment with the use of visually presented Polish compound words and simple words. The stimuli used in my experiment varied in terms of the degree of semantic transparency: half of the compounds were relatively fully transparent (e.g., *ręko·dzieło* ‘handicraft’) and the other half relatively fully opaque (e.g., *pędzi·wiatr* ‘roadrunner’); the simple words (i.e., the prime words) were the head nouns derived from the compounds, both from the transparent ones (*dzieło* ‘work’) or from the opaque ones (*wiatr* ‘wind’). The lemma frequency of occurrence of the compounds and simple words was kept constant with the use of the Polish Corpus PELCRA (Janus & Przepiórkowski 2007; Pęzik 2012).

2.1. Generating a set of transparent and opaque compounds in Polish

Initially, I selected 60 Polish compounds (more than half of which were assigned by me to have the status of transparent compounds) to be assessed by native speakers in terms of the degree of semantic transparency. The compounds were collected from the relevant literature on Polish compound words (Kurzowa 1976; Kolbusz-Buda 2014) as well as dictionaries (Bańko 2000; Dubisz 2008). The task of the participants was to judge how related the meaning of the components was to the meaning of the entire compound. This was done with the use of a 7-scale rating study (1 — unrelated, 7 — related). The question that was posed to raters was the following: "How related is the meaning of the entire compound to the meanings of its constituents?" (a similar technique was employed by Marelli, Crepaldi & Luzzatti 2009). Fifty-five undergraduate native speakers of Polish took part in the rating study, whose aim was to establish which compounds are perceived as transparent and which as opaque, since there is no such information readily available. As a result, 40 compound have been selected: 20 with the lowest score as semantically opaque, i.e., below 3.4, and 20 with the highest score as semantically transparent, i.e., above 5,4 (see Appendix B for the data from the rating study as well as for the results of the statistical analysis of the data).

2.2. Materials and methods

The aim of the present study was to test current approaches to the processing of morphologically complex words in a lexical decision task with masked priming employing Polish simple and compound words. One type of simple words and two types of compounds were targeted to assess whether there is the difference in reaction times for transparent compounds vs. opaque compounds (using masked semantic priming for the heads); and whether the transparent compounds are activated faster than opaque compounds.

There were four conditions included in the study, where the items in (i) were compared to those in (ii) and the ones in (iii) were compared to those in (iv):

(i) transparent compounds,
(ii) opaque compounds,
(iii) heads taken from transparent compounds,
(iv) heads taken from opaque compounds.

All heads taken from compounds were to be nouns (to which the primed words were related), as simple as they could be. In the case of transparent *bajkopisarz* 'fairy tell writer', the head *pisarz* 'writer' was formed in the process of V + *-er* derivation (i.e., *pisać* 'write' and *-arz* '-er'), but it also had its opaque equivalent — namely, *duszpasterz* 'priest', whose head *pasterz* 'shepherd' (i.e., *(wy)pasać* 'pasture' and *-erz* '-er') was also formed in the process of V + *-er* derivation.[5]

[5] I would like to thank one of the anonymous reviewers for this remark.

All experimental items were matched for length, the number of word formation processes, full-form frequency (confirmed by ANOVA test, p-value = .2167), congruity of prime/target phonemic and orthographic overlap, i.e., it was ensured that these two pairs of words did not share the same cluster of sounds or letters (within the four conditions). Compound heads were additionally matched for lemma frequency (p-value = .9567) and surface frequency (p-value = .7692). The frequency of heads was always higher than the frequency of compounds. The frequency of occurrence was obtained via the Polish Corpus, PELCRA NKJP 1.0. For the final study, a total of 40 compounds were chosen. The compounds were 3 or 4 syllables long (see Appendix A).

Additionally, the morphological complexity of the experimental material was counterbalanced: the number of morphologically complex transparent and opaque compounds was equal. There were also two compounds whose standard function in Polish is adjectival: transparent "jednoręki" ('one-armed') and opaque "złotousty" ('golden-mouthed person' or 'goldenmouth'), but they can also sometimes function as nouns ('one-armed person' and 'goldenmouth', respectively).

The experiment consisted in priming the head constituents of the mentioned compounds with the use of simple words semantically related to these head constituents (e.g., for *noga* 'leg' out of *HULAJNOGA* 'scooter', the related word was *ręka* 'arm'). As a neutral priming condition simple words semantically unrelated to neither of the constituents nor the whole compounds themselves were used (e.g., *blizna* 'scar' for *ĆWIERĆNUTA* 'quarter note'). As control items simple words (the heads of compounds) were used and they were also primed by semantically related words (e.g., for the simple word *kropka* 'dot', the prime word was *kreska* 'dash').

Due to a limited number of Polish opaque compounds with relatively high frequency of occurrence, the same items needed to be employed in the study for primed and unprimed condition. This solution, however, entails that the two sets (with primed and unprimed conditions) need to be analysed to test whether they are comparable, i.e., whether the effect between the sets (the so-called main effect) is significant. Nevertheless, it allows for testing a wide spectrum of Polish compounds with regard to semantic transparency, which gives the opportunity to compare the results for primed and unprimed conditions.

Such prime-target sets were composed of 40 related prime items paired with 40 compound words, 40 same related prime items paired with simple words (the heads of the compounds). To ensure that the subjects would not see the same prime item twice, the experiment was divided into two counterbalanced sets (the method of presentation of the material to participants is illustrated in Table 1).

Table 1: Examples of Prime and Target Items (the upper part — set A, the lower part — set B)

Targets	Example Prime (related)	Example Target
Transparent Compound	bestia ‘beast’	JEŻOZWIERZ ‘porcupine’
Opaque Compound	buzia ‘mouth’	ŻÓŁTODZIÓB ‘greenhorn’
Transparent Compound Head	wyraz ‘word’	SŁOWO ‘word’
Opaque Compound Head	powiew ‘puff’	WIATR ‘wind’
Transparent Compound	wyraz ‘word’	PUSTOSŁOWIE ‘bunkum’
Opaque Compound	powiew ‘puff’	PĘDZIWIATR ‘rolling stone’
Transparent Compound Head	bestia ‘beast’	ZWIERZĘ ‘animal’
Opaque Compound Head	buzia ‘mouth’	DZIÓB ‘beak’

As for the neutral condition 40 unrelated prime items were paired with 40 compound words (the stimuli are presented in Table 2).

Table 2: Examples of Prime and Target Items for the neutral condition

Targets	Example Prime (unrelated)	Example Target
Transparent Compound	blizna ‘scar’	ĆWIERĆNUTA ‘quarter note’
Opaque Compound	strzelba ‘shotgun’	DUSZPASTERZ ‘priest’

To establish the ratio of words to non-words equal 1:1, I used 40 non-existing filler items of two types: 20 pseudo-compounds composed out of existing long Polish words of foreign origin by altering or adding letters (e.g., the filler *OBWONILUTA* created out of *OBWOLUTA* ‘dust-jacket’), which were to counterbalance the target compounds, and 20 non-existing, but morphologically legal, monomorphemic words (e.g., *NAREK*), which were to counterbalance the simple words (the heads of compounds). Prime words which were paired with these filler items were random simple words (e.g., *stołek* — ‘stool’). See Appendix A attached to the paper for a full list of compound words used in the experiment.

2.3. Patricipants

The study included two stages: the primed condition and the unprimed condition. The total number of participants in both stages was 82. The participants were native speakers of Polish who were undergraduate students at the University of Wrocław (aged 19–24): 42 in the primed condition and 40 in the unprimed condition. All subjects had normal or corrected-to-normal vision. The total number of trials for each participant was 80. None of the subjects saw the same items twice.

2.4. Trial structure

The experiment was held in an isolated room with a computer. The stimuli were presented on a computer screen, centred horizontally in white characters (Arial font, size 24) on a black background. PsychoPy software (http://www.psychopy.org) was used to manage the presentation and to register the response times and accuracy of participants. They were instructed to judge whether an upper-case string of letters was a real word or not. In set A, subjects had to press the left arrow key to indicate that the letter string is a word, and the right arrow key that the letter string is a non-word; in set B, the left arrow key indicated a non-word, and the right arrow key a real word. The importance of response speed and accuracy were both stressed in the instructions.

Subjects were given ten practice trials prior to the target experiment as to both acquaint them with the rules of the study and to provide them a warm-up. The stimuli presentation was randomized for each participant.

Every trial started with a 500 ms forward mask — a string of hashtag symbols (i.e., #####), equal in the number of letters with the prime item which appeared afterwards for 60 ms[6] written in lower-case. The target word was then presented in capital letters, remaining on the screen until the response was given or for 2500 ms timeout (see, e.g., Masson & Bodner 2003, for the discussion of methodology).

2.5. Results

Six outliers exceeding the value of ± 2 standard deviations had to be removed in the primed condition in both experimental sets. Response times and accuracy rate values are presented in Table 3. The statistical analysis was carried out on 120 logarithmic transformed mean response times acquired from 30 participants (12 participants were removed as outliers — outliers were identified as the ones whose response time values were larger than +/-1,5 standard deviation from the mean). The distribution of the data is demonstrated below in Figure 1.

The differences between the two counterbalanced sets of items (Set A and Set B, see Table 1) seems to be large, but this is a between-subject variable, and with roughly 15 participants per set such differences are to be expected due to the sampling error. However, after analysing the differences between the two sets for the significant main effect, it was found that the two sets of items that the participants were tested on do not differ significantly from one another. Therefore, it was decided to analyse both sets together, rather than split the results into two separate groups. Only correct responses were used in the calculation of response times.

[6] The study was conducted with the use of a normal personal computer whose graphics card and monitor have designed refresh rates which, according to the indicated parameters, equals 60 ms.

The factor that was analysed is called TARGETS. It includes four types of target items: transparent compounds, opaque compounds, heads taken from transparent compounds and heads taken from opaque compounds.

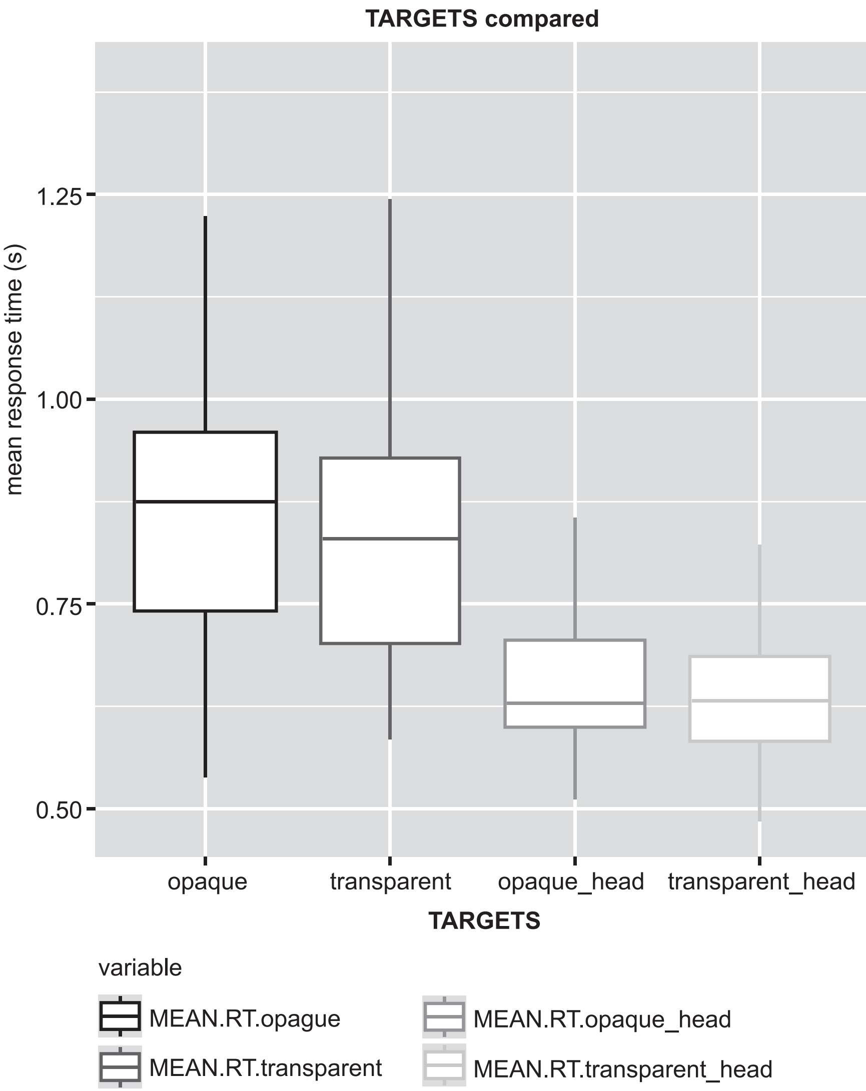

Figure 1: Mean response times TARGETS compared

A mixed-model for paired measurements was built for analysing the logarithmic transformed mean response times, which, along with 95% confidence intervals for the tested TARGETS are demonstrated below in Figure 2.

Mixed model ANOVA results indicated significant main effects for TARGETS. The assumptions of sphericity of variances was violated (W = 0.443, p = .0006) for the TARGETS main effect, therefore Greenhouse-Geisser correction was applied (F(1.98, 55.44) = 72.449, p < .001).

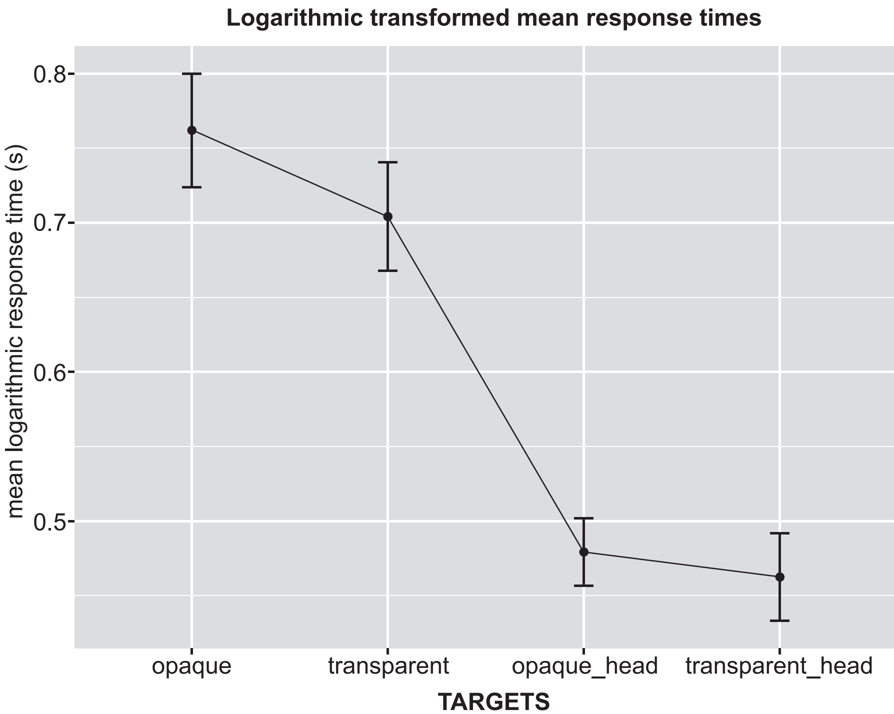

Figure 2: Logarithmic transformed mean response times TARGETS compared

As far as the main effect for TARGETS is concerned, pairwise comparisons were significant in the case of opaque vs. transparent compounds (p = .045), transparent compounds vs. opaque compound heads (p < .001), opaque compounds vs. transparent compound heads (p < .001), opaque compounds vs. opaque compound heads (p < .001), and transparent compounds vs. transparent compound heads (p < .001). For the comparison between opaque compound heads and transparent compound heads no significant difference was found (p = 1).

Table 3: Masked priming of head / word-final position

TARGETS	Response time in ms. (error %) Mean Difference		
	Transparent	Opaque	
Compound (primed)	889 (2.9%)	952 (8.6%)	+63*

Compound Head	721 (1.4%)	701 (0.7%)	-20
	Compound	Compound Head	
Transparent	889 (2.9%)	721 (1.4%)	-168**
Opaque	952 (8.6%)	701 (0.7%)	-251**

* p < .05. ** p < .01.

Table 3. shows reaction times for the different experimental TARGETS. The priming effect[7] was found for comparisons with the mean difference less than .05 (the symbol * indicates the priming effect, i.e., p < .01, whereas the symbol ** indicates the robust priming effect, i.e., p < .05).

As for the unprimed condition, the data was analysed using R: A language and environment for statistical computing (R-core Team 2013). In the experiment reciprocal response times are reported. Reciprocal transformation on response times was used to make their distributions normal or close to normal. After the reciprocal transformation was applied there were no longer any outlying data points, therefore the analysis is carried on the full data set: 40 participants. Mean reciprocal response times are illustrated graphically in Figure 3.

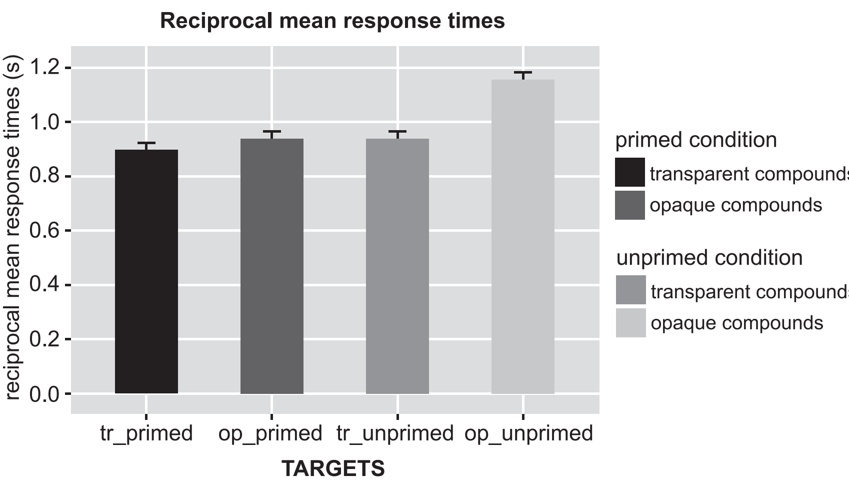

Figure 3: Reciprocal mean response times TARGETS compared

To determine the differences between the experiment conditions, a repeated measurements one-way ANOVA analysis, using the linear and nonlinear mixed effects models (Pinheiro, et al. 2017) package was conducted. The results of the analysis show that reaction times are not dependent on the differences between

[7] This priming effect consists in the comparison of reaction times to transparent and opaque compounds in lexical decision under condition of head priming.

the conditions ($\chi^2(3) = 1.62$, $p = .471$) and therefore the juxtaposition of the primed and unprimed conditions is valid.

Table 4: Response times for primed and unprimed conditions within TARGETS

TARGETS	Response time in ms. (error %) Mean Difference		
	Transparent	Opaque	
Compound (primed)	889 (2.9%)	952 (8.6%)	+63*
Compound (unprimed)	954 (3.0%)	1163 (8.3%)	+209**
	Compound (primed)	Compound (unprimed)	
Transparent	889 (2.9%)	954 (3.0%)	+65*
Opaque	952 (8.6%)	1163 (8.3%)	+211**

* $p < .05$. ** $p < .01$.

What the data of the experiment demonstrate is that the type of compound heads (i.e., simple words taken from transparent or opaque compound words) does not significantly affect the processing. When the same simple words function as heads of compound words, however, their processing takes more time (i.e., is more difficult) for both transparent and opaque compounds. After comparing the two groups of compounds, the results indicate that transparent compounds are processed faster than opaque ones, which implies that semantic transparency influences the processing of Polish compound words. The priming effect is different for transparent and opaque compounds and, furthermore, there is a significant difference between these two TARGETS. When the compounds are preceded by a semantically unrelated prime, the processing takes more time than in the case of the same compounds preceded by related primes. The results obtained in this study for Polish compounds are similar to those reported by Bronk et al. (2013) for German compound words using the standard priming technique.

3. Discussion

The reported study aimed at the expansion of our understanding of the processing of multimorphemic words — namely, compound words. Two of the many factors that are believed to affect the choice of the primary route (storage vs. decomposition) during visual identification of complex words are semantic transparency and frequency of occurrence. The study focused on the issue of whether Polish compounds (at least some) are parsed into their constituent morphemes during word identification, and, if so, are there any additional costs which are entailed by this decomposition. Moreover, the possible influence of semantic transparency on the processing of compounds was tested.

There were some cases in which response times were shorter for compounds than for simple words. This can be explained by fast and effective compound representations on the lemma level. As the head start in the processing was revealed for both opaque and transparent compounds, this indicates that compounds in general are accessed before semantics plays a role.

The obtained results are consistent only with one of the two current compound processing approaches described in section 2 and yet only to certain degree. For the convenience of the reader, I will briefly recapitulate the key tenets of these two models and explain their (lack of) compatibility with the current results. The models are Ji et al.'s (2011) meaning computation approach and Libben's (1998) conjunctive activation approach. The results are not compatible with the former approach because there is no negative priming effect found for opaque compounds. The second approach — CAA — allows for different response times caused by the difference in the degree of semantic transparency: transparent compounds are responded to faster than opaque compounds. However, it states that the lack of transparency in the case of opaque compounds should not affect the processing. In my outcomes, the priming effect found for primed and unprimed conditions of opaque compounds was significant ($p < .05$) and positive. This might be explained by the fact that the composed meaning needs to be rejected for the benefit of the stored representation, which in turn triggers longer response times, accepting the possibility of decomposition for both transparent and opaque compounds.

Let us now consider the obtained results through the lens of traditional approaches to morphological processing: Taft's (2004) obligatory decomposition, Butterworth's (1983) full listing-model and Giraudo and Grainger's (2000) supralexical model. Taft' model claims that the representation of words (both free and bound morphemes) on the lemma level associate functional properties (i.e., syntactic and semantic ones) with representational properties (i.e., phonological and orthographic ones). In accordance with this model, transparent complex words (e.g., *departing*) do not require their own representations as the functional properties of the words can be determined entirely from their constituents (i.e., *depart-* and *-ing*). Opaque complex words (such as *department*), however, are connected with functional properties which cannot be inferred purely from their constituents (i.e., the stem *depart-* and the suffix *-ment* in *department* attributes to "section" or "area", and not "the action of leaving and starting a journey"). Thus, opaque complex words need their own lemma representations to associate the form with its functional properties. Yet the existence of the lemma representation needs not necessarily imply that the particular opaque complex words has a whole-word representation (e.g., the lemma of *department* can still be accessed through its constituents, i.e., *depart-* and *-ment*). Taft's approach then proposes that: (i) morphological parsing is obligatory for all complex words, both transparent and opaque, (ii) the route that is selected for the processing of morphologically complex words depends on semantic transparency, and (iii) decomposition happens before the lexical access. The crucial inference of this approach is that decomposition does not function in isolation: to access the full-word representation, the constituents of the complex word need to be activated either by functional or representational properties.

The outcomes from the present study show that masked priming is influenced by the degree of semantic transparency: the semantic relations between the prime items and the target items significantly affected the response times ($p = 0.45$). This indicates that masked semantic priming was stronger for transparent than for opaque compounds. Thus, the results are consistent with the model proposed by Taft (2004). Yet the masked priming effect with manipulations of semantic transparency was rejected by former studies (e.g., Orfanidou et al. 2010; Amenta & Crepaldi 2012), which suggested that the masked priming technique encourages a morpho-orthographic decomposition (for discussion see Rastle et al. 2004). This sort of decomposition is believed to atomize all morphologically complex words into their constituents. This approach, however, seems not to be evident for the case reported here.

Butterworth's (1983) full-listing model suggests that morphemes are not predominantly responsible for complex word processing. Butterworth assumes that all derived and inflected forms of the same root are separately stored in the mental lexicon and are connected with one another by associative links. This procedure involves activation of the entire word (i.e., its complete phonological or orthographic form) that is stored in the mental lexicon. The operations engaged in the listing model are fast and associative and do not depend on external factors, such as semantic transparency. The obtained results are not consistent with this model because there are significant differences between transparent and opaque compounds.

The last model being considered here — the supralexical model — offers another stand on the processing of morphologically complex words. It suggests that all complex words are first activated via a full-form representation which occurs prior to the activation of the components. The procedure would, however, involve longer response times for transparent compounds as, according to this model, they would first follow the listing route and — unless they are stored — they would change the route to the decomposition one, which would slow down the overall processing time.

Yet the processing of complex words might be in fact more complicated than has been thus far presupposed. Let us go one step further: it may be the case that transparent compounds do follow the mentioned processing procedure, while opaque compounds follow an even more complex one: they are first activated as a full-form representation but even though they are found in the mental lexicon, they are still forced to be decomposed, but decomposition and reassembly do not construct an understandable and world-acceptable meaning and thus it has to be rejected for the benefit of the traditional, stored representation. But the entire procedure is longer for opaque compounds than for transparent compounds. Therefore, if we apply the above reasoning, which extends the assumptions made via the supralexical model, it could possibly explain the obtained results.

The internal structure of compound words consists of a variety of internal relationships between their constituents. One of such relationships, which has been explored in the present study, is semantic transparency which is displayed in the semantic relatedness between components and the whole compound. When the components pass on their semantic (and/or syntactic) properties to the whole structure, the compound is known to be transparent. If they do not, the compound is known to be opaque. The results point to the conclusion that this relationship affects the processing of Polish compound words. This is just a part of the answer to the first research question addressed in this paper. There are certainly more issues at hand. To outline some important areas for future interest: the function of the non-head — whether argument-head or modifier-head — should be more thoroughly explored.

Coming back to the second research question: as far as the issue of semantic transparency is concerned, the obtained outcomes may be explained in two-fold way. First, most of the studies with the use of the masked priming paradigm has concentrated on languages such as English, Dutch or Italian, and the present study focuses on compounds in the Polish language, for the first time. On the one hand, Polish derivation and affixation is more productive than, for example, the English one but, on the other, compounding in Polish is less productive than in English and establishes a modest part of language (see Szymanek 2012, who holds a similar view). As was mentioned in section 2, the type of language may have a crucial role in determining the processing of language. For instance, the mechanisms employed by Polish native speakers for the processing of compound words can be of a different sort from the ones employed by English native speakers. Second, morpho-orthographic decomposition offers an account that all compounds are decomposed but they follow different processing paths. The data from the present experiment propose that Polish transparent and opaque compounds follow different processing routes, but it does not necessarily imply that it occurs at decomposition level. The two types of compounds may initially be decomposed and only after that, they take different paths with respect to the semantic agreement (for transparent compounds the processing cost is lower) or semantic disagreement (for opaque compounds the processing cost is higher) between the constructed meanings of constituents, the constructed meaning of the entire compound and its traditional interpretation.

4. Conclusion

To sum up, the results provide evidence that the compound processing in the Polish language is influenced by semantic transparency. The role of semantic transparency is evident from the difference in response times in the case of transparent and opaque compounds. This can be explained by the beneficence of the constituents' semantics to the activation of whole-word representation. The response times elicited for opaque compounds were significantly longer: this may be accounted for in two ways: either opaque compounds are not decomposed, or there is the so-called reassembly stage after decomposition, in which the decomposed forms need to be constructed. The approach that best reflect the full pattern of results of this study is Taft's (2004) obligatory decomposition, but two other approaches are also partially compatible: Libben's (1998) conjunctive activation approach and Giraudo and Grainger's (2000) supralexical model. However, the approaches which are incompatible with my study are Butterworth's (1983) full-listing model and Ji et al.'s (2011) meaning computation approach.

The present research demonstrates that compound words may be used in connection with the organization of our mental lexicon and its relation to grammar, which turns out to be one of the most fundamental questions, irrespectively of the adopted theoretical stand. Compound processing can furthermore settle the heated and so far unresolved linguistic debate — the extent to which the meaning is expressed by grammatical structures and to which by lexical units. This is just one of the many problems in this yet under-studied area of compound processing.

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Appendix A

Table A1: Response times and frequency of transparent compounds in Set A

Compound	Lemma frequency	Response time in ms. (error %)
	mean: 227,2	all mean: 925
BAJKOPISARZ ‘fairy tale writer’	78	855 (0%)
RĘKODZIEŁO ‘handicraft’	574	847 (0%)
ĆWIERĆNUTA ‘quarter note’	24	934 (14%)
OCZODÓŁ ‘eye socket’	414	898 (0%)
STONOGA ‘centipede’	191	800 (0%)
PAROWÓZ ‘steam engine’	658	841 (0%)
CUDZYSŁÓW ‘quotation marks’	794	823 (0%)
OGNIOMISTRZ ‘ordnance technician’	155	1067 (14%)
PUSTOSŁOWIE ‘bunkum’	111	1257 (10%)
KOŚCIOTRUP ‘skeleton’	275	800 (0%)

Table A2: Response times and frequency of transparent compounds in Set B

Compound	Lemma frequency	Response time in ms. (error %)
	mean: 227,2	all mean: 925
GWIAZDOZBIÓR ‘constellation’	336	794 (0%)
DWUKROPEK ‘colon’	103	843 (5%)
JEŻOZWIERZ ‘porcupine’	30	923 (5%)
PŁASKOWYŻ ‘plateau’	340	991 (0%)

NOSOROŻEC ‘rhinoceros’	276	828 (0%)
MARSZOBIEG ‘endurance march’	57	1002 (5%)
ŻYWOPŁOT ‘hedge’	560	823 (0%)
JEDNORĘKI ‘one-armed person’	165	820 (0%)
PÓŁGŁÓWEK ‘halfwit’	136	827 (0%)
MEBLOŚCIANKA ‘wall unit’	188	908 (0%)

Table A3: Response times and frequency of opaque compounds in Set A

Compound	**Lemma frequency**	**Response time in ms. (error %)**
	mean: 227,2	all mean: 925
PĘDZIWIATR ‘roadrunner’, lit. ‘rush’ + ‘wind’	124	808 (5%)
DUSZPASTERZ ‘priest’, lit. ‘soul’ + ‘shepherd’	1015	991 (5%)
PRZEBIŚNIEG ‘snowdrop’, lit. ‘break through’ + ‘snow’	84	937 (0%)
ZŁOTOUSTY ‘golden-mouthed person’, lit. ‘golden’ + ‘mouth’	98	1120 (5%)
ZAWALIDROGA ‘obstacle’, lit. ‘fall’ + ‘road’	109	1065 (24%)
DUSIGROSZ (‘penny pincher’, lit. ‘strangle’ + ‘grosz = Polish currency’	36	967 (14%)
ŻÓŁTODZIÓB ‘greenhorn’, lit. ‘yellow’ + ‘beak’	146	902 (0%)

BAWIDAMEK 'ladies' man', lit. 'entertain' + 'lady'	46	1006 (29%)
OBIBOK 'lazybones', lit. 'lounge around' + 'side'	124	865 (14%)
DROBNOUSTRÓJ 'micro-organism', lit. 'small' + 'system'	348	994 (0%)

Table A4: Response times and frequency of opaque compounds in Set B

Compound	Lemma frequency	Response time in ms. (error %)
	mean: 227,2	all mean: 925
OBIEŻYŚWIAT 'globetrotter', lit. 'run around' + 'world'	134	912 (5%)
WODOGŁOWIE 'hydrocephaly', lit. 'water' + 'head'	80	826 (5%)
WŁÓCZYKIJ 'rolling stone', lit. 'roam around' + 'stick'	94	964 (0%)
HULAJNOGA 'scooter', lit. 'fribble' + 'leg'	253	814 (5%)
MOCZYMORDA 'soak', lit. 'soak' + 'mug'	43	1208 (10%)
LEKKODUCH 'happy-go-lucky person', lit. 'light' + 'spirit'	107	800 (5%)
ŁAMIGŁÓWKA 'puzzle', 'charade', lit. 'break' + 'head'	403	763 (0%)
GRYZIPIÓREK 'petty official', lit. 'bite' + 'feather'	70	1289 (19%)
CZARNOZIEM 'charnozem', lit. 'black' + 'earth'	92	956 (10%)

GRAFOMAN ‘scribbler’, lit. ‘graphic arts’ + ‘mania’	217	950 (19%)

Appendix B
See Appendix A for English translations.

Table B1: The results of the online questionnaire

Transparent compounds	**Transparency rating**	**Opaque compounds**	**Transparency rating**
bajkopisarz	5.6000	pędziwiatr	2.9455
rękodzieło	5.9818	duszpasterz	3.3727
ćwierćnuta	5.0909	przebiśnieg	3.3818
oczodół	6.0182	złotousty	2.6464
stonoga	5.6545	zawalidroga	3.2727
parowóz	5.5818	dusigrosz	3.2364
cudzysłów	5.6364	żółtodziób	1.8000
ogniomistrz	5.4021	bawidamek	3.1545
pustosłowie	5.7273	obibok	2.2000
kościotrup	5.8182	drobnoustrój	3.2455
gwiazdozbiór	6.2545	obieżyświat	2.3091
dwukropek	6.1455	wodogłowie	3.4273
jeżozwierz	5.9272	włóczykij	2.7818
płaskowyż	5.8909	hulajnoga	3.1727
nosorożec	5.3091	moczymorda	3.2091
marszobieg	5.7455	lekkoduch	3.0364
żywopłot	5.4727	łamigłówka	3.1636
jednoręki	6.2909	gryzipiórek	2.2545
półgłówek	5.5636	czarnoziem	2.4182
meblościanka	5.6182	grafoman	2.9091

Table B2: Standard deviation, standard error of mean and p-value

Group	**Transparent compounds**	**Opaque compounds**
mean	5.7365	2.8969
standard deviation (SD)	0.3107	0.4705
standard error of mean (SEM)	0.0690	0.1052
p-value	$p < 0.0001$	