Head position and the mental representation of nominal compounds: a constituent priming study in Italian.

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Abstract

There is a significant body of psycholinguistic evidence that supports the hypothesis of an access to constituent representation during the mental processing of compound words. However it is not clear whether the internal hierarchy of the constituents (i.e., headedness) plays a role in their mental lexical processing and it is not possible to disentangle the effect of headedness from that of constituent position in languages that admit only head-final compounds, like English or Dutch. The present study addresses this issue in two constituent priming experiments (SOA 250ms) with a lexical decision task. Italian endocentric (head-initial and head-final) and exocentric nominal compounds were employed as stimuli and the position of the primed constituent was manipulated. A first-level priming effect was found, confirming the automatic access to constituent representation. Moreover, in head-final compounds data reveal a larger priming effect for the head than for the modifying constituent. These results suggest that different kinds of compounds have a different representation at mental level: while head-final compounds are represented with an internal head-modifier hierarchy, head-initial and exocentric compounds have a lexicalised, internally flat representation.

Keywords: compound nouns, headedness, constituent priming, lexical morphology

According to linguistic theory, words have internal structures; i.e., the elements that constitute each individual word are hierarchically related. These elements, known as morphemes, are defined as the smallest linguistic unit with a semantic meaning or function (Bloomfield, 1933). The question as to whether morphemes are independently stored in the mental lexicon and are used during word processing has been much debated in psycholinguistics; for example, is the derived word *unbreakable* stored as a whole and accessed as such or are its morphemes *un-*, *break* and *-able* stored separately and the word *unbreakable* composed (or decomposed) on-line? And how is this processing governed at mental level? Do different word structures (e.g., $[\mathit{un}_{\mathrm{aff}}[[\mathit{break}]_{\mathrm{v}}[\mathit{able}]_{\mathrm{DS}}]_{\mathrm{adj}}]_{\mathrm{adj}}$ versus $[[[\mathrm{re}]_{\mathrm{aff}}[\mathrm{fill}]_{\mathrm{v}}]_{\mathrm{v}}\mathit{able}_{\mathrm{DS}}]_{\mathrm{adj}}$) underlie different types of processing at mental level?

Both parsing and listing models have been proposed to account for the data obtained through experimental research. Taft and Forster (Taft & Forster, 1975; Taft, 2006) assume that the units stored in the mental lexicon are morphemes and therefore multimorphemic words have to be processed along a decompositional route. According to Butterworth (1983), who proposed a non-decompositional account, morphemes do not have a predominant role in complex word processing: all inflected and derived forms of a single root are independently stored in the lexicon and are related to each other by associative links. However, segmentation and storage models of complex words are no longer considered incompatible, and dual route models have been proposed. These models are based on the contraposition between full-listing processing of irregular forms and full-decomposition of regular inflectional forms (e.g., Marslen-Wilson, Tyler, Waksler & Older, 1994; Marslen-Wilson & Tyler, 1997), or full-listing of derived words and full-decomposition of inflected words (Jackendoff, 1975; Miceli

& Caramazza, 1988). Schreuder & Baayen (1995) suggested that both a direct and a parsing processing are involved from the very beginning of lexical access (see also Baayen, Dijkstra, & Schreuder 1997, Baayen, Burani, & Schreuder 1997, Luzzatti, Mondini, & Semenza 2001). This model usually assumes the two routes to be independent and in competition (but see Baayen & Schreuder, 2000). More recently, a multi-route, interactive model of complex word processing has been proposed (Kuperman, Bertram & Baayen, 2008; Kuperman, Schreuder, Bertram & Baayen, 2009). Applying the Maximization-of-Opportunity theory proposed by Libben (2006), this model assumes an early simultaneous access to multiple sources of information (including whole-word, constituent morphemes and morphological families) and multiple processing mechanisms in complex word recognition.

Models of morphological processing are based primarily on evidence from studies on derived and inflected words; the properties of compound words, on the other hand, are different from those of the complex words considered so far, and therefore accounting for their processing on the basis of certain of these models is not straightforward (Libben, 1998). Compounds are formed from the concatenation of various words (constituents) rather than being composed of a single root and one or more affixes. The constituents are free elements, i.e., they can stand alone and therefore the mental lexicon must contain a representation of all the constituents of a compound. As a consequence, compounds can be logically accessed in one of three ways: i) through their whole representation, ii) through the representation of the first constituents, iii) through the representation of the second constituents (Sandra, 1990), as either could serve as an entry key for the compound representation.

Indeed, it is probable that certain compound representations are listed in the mental lexicon since the meaning of a compound may not be fully predictable through the meaning of its constituents. On the one hand, the meaning-to-form relation is often arbitrary; on the other hand, the relation between constituents is idiosyncratic, because it is not determined by the word formation process. Badecker (2001) provided an effective example in *horse pill*; although the meaning of its constituents are related intuitively to the meaning of the compound, the structure does not provide any indications with which to interpret the way the meaning of these constituents relates to the meaning of the compound word (e.g., *fertility pill*, *horse pill*, *garlic pill*, *nausea pill*).

Not only do compounds vary in terms of *how* their meaning derives from that of the constituents, they also differ in the *extent to which* their semantics are predictable from the constituents (e.g. *carwash vs. fleabag*). Sandra (1990) highlighted the importance of semantic transparency in compound word processing, employing a semantic priming paradigm in a lexical decision task with Dutch compounds. He found that response latencies for a target compound preceded by a prime word semantically related to one of its constituents (e.g. *moon* for *Sunday*) were significantly faster only for transparent targets; moreover, when a priming effect emerged, it was independent of the position of the primed constituent. These results contrast both with an automatic parsing device and with access through one of the constituents, and favour access to both constituents modulated by the semantic traits of the whole compound.

Although Sandra's (1990) results throw doubts on automatic access to constituents, a number of studies (Zwitserlood, 1994; Jarema, Busson, Nikolova, Tsapkini & Libben, 1999; Libben, Gibson, Yoon & Sandra, 2003; Shoolman & Andrews, 2003) found a priming effect for both transparent and opaque compounds, thus supporting the hypothesis of a routine process of (de)composition or, at least, a link between the representation of whole compound words and of their constituents. These results were obtained through a constituent priming paradigm in which the constituents of the target compound were used as prime words. It has been suggested that the discrepancy between these data and Sandra's is to be imputed to the different methodologies adopted (Libben et al., 2003): the two types of priming would affect different levels of processing. This interpretation is also supported by the results obtained by Shoolman & Andrews (2003) who used a masked priming technique, in which both constituents primed target compound words equally. These data support the hypothesis that automatic decomposition routinely takes place at an early level of processing and are consistent with Libben's model (1998) that assumes a lexical and a conceptual level to account for semantic transparency effects. Both lexical and conceptual levels contain a representation of the whole compound and independent representations of its constituents; the difference between the two levels lies in the links between representations. At the lexical level the representation of a compound is always linked to the representations of its constituents, regardless of semantics, which explains the ever-present priming effect in constituent-priming experiments. At the conceptual level, however, the manner in which a compound is represented depends on its semantic relationship: while transparent compounds are linked to their constituent representations (which explains the evidence obtained by Sandra, 1990), opaque compounds are not, and cannot therefore be primed by semantically related words.

Even if a certain degree of consensus has been reached on the decomposition of compound words, the role of the constituents' properties in compound-word processing remains controversial. Early psycholinguistic studies provide evidence of access via the first constituent: Taft and Forster (1976), working with a lexical decision task, found that real words at the beginning (but not at the end) of non-word compounds (e.g., *footmilge* vs. *trowbreak*) delay response latencies consistently with the hypothesis of a left-to-right parsing device; moreover, compounds with a high-frequency initial constituent yielded faster response times than compounds with a low-frequency initial constituent. Other studies (Andrews, 1986; Juhasz, Starr, Inhoff & Placke, 2003) have confirmed the constituent frequency effect on response latencies for compound words. Juhasz et al. also noted that a final-constituent effect is effective through a number of tasks (e.g., lexical decision word naming) and different dependent variables (response times and eye fixation). It is worthwhile noting that in English the second constituent is always the head of the compound, i.e. the constituent that transfers its semantic and lexical properties (e.g., grammatical class) to the whole, but its actual role in the processing of compounds remains unclear. When the meaning of the head is related to the meaning of a compound (i.e., the head is transparent) the target compound is easier to process in a lexical decision task, regardless of the semantic transparency of the modifier (Libben et al., 2003). These results suggest that the likelihood of a compound to be interpreted as a type of X, where X is the head of the compound, affects the manner in which it is represented in the lexicon. However, the lack of priming difference between head and modifier (Libben et al. 2003) indicates that the results cannot be explained by activation of the compound head alone.

These latter results were obtained from a study carried out with native English speakers; English, like Dutch (the languages most studied in psycholinguistics), is a right-headed language, i.e. the morphological head of complex words is always the rightmost element (Williams, 1981, but see Lieber & Baayen, 1993). It is therefore impossible to disentangle the pure positional effect, i.e., being the rightmost constituent, from a real headedness effect. In Romance languages compounds may be either head-final or head-initial; these languages are thus best suited to disentangle the effect of position from that of headedness. Jarema et al. (1999) employed a methodology similar to that used by Libben et al. (2003) in a study with native French speakers. They found a larger priming effect for head-initial compounds when the first constituent was primed, while the priming effect was only slightly larger for head-final compounds when the second constituent was primed; in other words, there seems to be a stronger headedness effect on priming in head-initial compounds. These results could support the hypothesis of an interaction of two factors, i.e., the salient position of the first constituent due to a left-to-right parsing device and the importance of the morphological head, which affects the way compound words are accessed. An ERP study carried out with Italian speakers (El Yagoubi, Chiarelli, Mondini, Perrone, Danieli, & Semenza, 2008) provided further results in support of the role of the morphological head during the processing of compounds: head-final compounds elicited a larger P300 component than head-initial compounds. Since it has been suggested that P300 reflects an update of context in working memory, this would suggest that the information contained in the head constituent plays a crucial role. Despite the electrophysiological difference, this working memory update does not correspond to an RT increase for head-final compounds.

In conclusion, although there is a fair number of studies concerning the processing of compound nouns, the results obtained do not constitute a coherent frame; in addition, together with data supporting early automatic decomposition affecting all classes of compounds there is also evidence of different processing for transparent and opaque compounds, which may suggest several processing levels and types of representation (see Libben, 1998, Taft & Ardasinsky, 2006). However, it is still unclear whether the properties of the constituents (especially position and headedness) actually affect the processing and, if so, whether this occurs only at specific levels of representation.

The aim of the present study is to assess how constituent position and headedness modulate the processing of compounds, exploiting the Italian compounding system which permits disentanglement of the roles of these two variables. This issue was initially addressed in a constituent priming experiment with lexical decisions regarding noun-noun (NN) and noun-adjective (NA) Italian compounds; the same procedure was then applied to a second experiment regarding verb-noun (VN) compounds, which are the most productive nominal compounds in Italian.

Experiment 1: Constituent Position and Headedness in Endocentric Nominal Compounds

A constituent priming paradigm with a lexical decision task was used to study the processing of noun-noun and noun-adjective compounds and to investigate how constituent position and headedness influence the priming effect. Comparisons of target decision latencies subsequent to the presentation of morphologically related and unrelated primes were mainly used to assess the presence of decomposition processes.

Materials and Methods

Participants.

Thirty-two participants (5 males and 27 females) took part in this experiment (mean age = 23±3, mean education = 18±3). All were native Italian speakers with normal or corrected-to-normal vision and no reading disorders; they were attending the University of Milano-Bicocca as either undergraduates or postgraduates, and participated in the study in exchange for practical credits or as volunteers.

Materials.

In Italian, NN compounding is not a productive process as in Dutch or English, and thus compounds with similar structure (NA and AN compounds) had to be included in order to obtain a sufficiently large sample of head-initial and head-final nominal compounds (an analogous procedure was adopted in studies carried out on other Romance languages, e.g. Jarema et al., 1999).

Forty-eight compounds (7 AN, 7 NA, 34 NN) were used as experimental targets; half were head-initial (e.g., *pescespada*, 'swordfish', lit. 'fish'+'sword') and half head-final (e.g., *astronave*, 'spaceship', lit. 'star'+'ship'). Head-final and head-initial compounds were matched for lemma and form frequency of both compounds and constituents, but differed slightly in length (9.7 vs 10.6 letters, T[46]=2.3 p=.03). They were also matched for semantic transparency, which had been evaluated by 25 undergraduate students in a preliminary study; the participants were asked to rate each compound, assessing the extent to which its meaning was predictable from the meanings of its constituents on a four-point rating scale ranging from "very unpredictable" to "very predictable”. The orthographic neighbourhood size of the target words was very small (0 to 1) and so no balancing was required.

Four different prime types were paired with each probe compound: (1) the first constituent (*photo/FOTOCOPIA,* ‘photo’/’PHOTOCOPY’); (2) the second constituent (*copia/FOTOCOPIA,* ‘copy’/’PHOTOCOPY’); (3) a control word for the first constituent (*foro/FOTOCOPIA,* ‘hole’/’PHOTOCOPY’); (4) a control word for the second constituent (*coppa/FOTOCOPIA,* ‘cup’/’PHOTOCOPY’). Control words were semantically unrelated to the whole compound and to the two constituents; both control primes were very similar to the paired constituent prime (70% of letters were the same and fell in the same position). Constituent primes and control word primes were matched for lemma frequency, form frequency, length and neighbourhood size.

Forty-eight pseudo-compounds were created (e.g., **nasoponte,* ‘nose’+’bridge’) as targets for the nonword trials; none of the components of the 48 meaningful target compounds was used for this purpose. As in the experimental word set, 50% of the pseudo-compounds were primed by their first constituent (or a similar control word), whereas the remaining 50% were primed by their second constituent (or a similar control word).

In order to avoid list effects triggering an overgeneralization of decompositional processing (see Andrews, 1986), 48 mono-morphemic filler trials were introduced, of which 50% were three-to-four syllable real nouns (e.g., *elefante*, ‘elephant’) and 50% were pseudo-words obtained by changing one or two letters of real nouns of the same length (e.g., **toccuiso* from *taccuino*, ‘notepad’). Filler targets were all primed by semantically unrelated real words.

Experimental design and procedure.

Four different experimental lists were set up, each containing the 48 probes paired with one of the four primes so that no target was repeated twice in any of the lists. Each list was internally counterbalanced, using 12 first-constituent primes, 12 second-constituent primes, 12 control primes for the first constituent and 12 control primes for the second constituent. Similarly, no prime was repeated twice within any experimental list. Trials were divided in two balanced blocks (with an interval in between).

The experiment was held in a room with dimmed lighting, using a computer. The stimuli appeared in the centre of a computer screen in black characters on a white background. E-Prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002) was used to control the presentation of the stimuli and for the registration of the response times. Participants were instructed to judge if an upper-case letter string appearing on the screen was a real word; they were also told to ignore lower case words appearing briefly before the target words. If they considered that the letter string was a word, they had to press a button using the index finger of their dominant hand, while non-words were indicated by pressing another button with the index finger of their non-dominant hand (handedness was evaluated by the Edinburgh Inventory Test, Oldfield, 1971). The importance of both speed and accuracy was stressed during the instructions.

Participants were given eighteen practice trials prior to starting the experiment, and eight trials were inserted at the beginning of the experimental blocks as warm-ups.

Trial Structure.

Each trial started with a fixation point (+) for 500 ms, followed by the prime (presented in lower case; e.g. *foto* – 'photo') for 250 ms and by a mask for 50ms. The target was then projected in capital letters (e.g. *FOTOCOPIA* – 'PHOTOCOPY'), and remained on the screen until the response was given. Response times (RTs) were registered starting from the onset of the target. The inter stimulus interval (ISI) was 1500 ms.

Data analysis.

Inverse RTs (used to normalize the distribution; Van Zandt, 2002) and response accuracy were analyzed employing mixed-effects models (Baayen, Davidson, & Bates 2008). The RT analysis was performed only on correct responses. Responses with particularly long latencies (defined as two or more SD from RT mean by participants) or with RTs faster than 300 ms were considered as outliers and were excluded from the analysis; 113 datapoints were thus excluded. The dependent variable was dichotomous in the accuracy analysis, hence a logistic model was applied (Jaeger, 2008).

(INSERT TABLE 1 ABOUT HERE)

Three factors were considered (see Table 1). Participant and item were introduced as crossed random effects.

Results

(INSERT FIGURE 1 ABOUT HERE)

Figure 1 summarizes the mean priming effects obtained from the diverse experimental conditions. The RT analysis started from a full factorial model, which was then simplified by removing all fixed effects that did not contribute to the overall goodness of fit of the model, using $|t|<1.0$ as a criterion; if more than one *t*-value was below the criterion, the effect with the lowest *t* was removed first. A check was made at each step to ensure that the removal of the parameter did not significantly affect significantly the goodness of fit of the model. The procedure led to the final fixed-effect part of the model including (i) PT as a first-level effect, (ii) the interaction between H and PT, and (iii) the interaction between H, PC and PT. The intermediate steps of the model simplification procedure are illustrated in greater detail in Appendix A. Initially, the random-effect structure included the effects of items and participants on the intercept, after which a random effect of participants on PT and of items on the third-level interaction were added, as they determined a significant increase in the model goodness of fit (see Appendix A). These additional random factors indicated that (i) participants varied in their general sensitivity to facilitation, so that the overall amount of priming differed across participants, and (ii) the interaction between H, PC and PT was modulated by the general characteristics of the items. Residuals did not correlate with the fitted values (r = .07), showing that the model is unbiased.

(INSERT TABLE 2 ABOUT HERE)

The estimated parameters of the final model are reported in Table 2 together with their statistics; they are expressed in -1000/RT as the model was fitted using the inverse

RTs to attain a higher statistical power. The table also provides the estimated parameters of the same model applied to the untransformed RTs. The statistical significance of individual fixed effects is normally evaluated using a Markov chain Monte Carlo sampling in mixed-effect modelling (Baayen et al., 2008), but this procedure has not yet been implemented in the R environment for models including random slopes. Therefore the alternative method suggested by Baayen (2008) was used, which estimates the degrees of freedom by subtracting the number of fixed-effect parameters included in the model (3) from the total number of data-points considered (1287). As shown in Table 2, both the PT effect and the third-level interaction turned out to be significant. Thus the model indicated an overall priming effect of about 53 ms (the estimated parameter for PT) and that this effect is larger when priming involves the head of head-final compounds (see the estimated parameter for H:PC:PT).

(INSERT FIGURE 2 ABOUT HERE)

Figure 2 shows the priming effect on the percentage of accuracy for the different experimental conditions. Accuracy was analysed using a mixed effects model, adopting the same procedure as above. PT and PC were included as fixed effects and items and participants were included as random effects on the intercept. A significant PT effect was found (estimated parameter .96, z=4.53, p<.001): accuracy was greater on the lexical decision task when the target was primed by one of its constituents than when it was primed by a control word.

Discussion

The overall constituent priming effect revealed by both the RT and the accuracy analyses indicates that the recognition of NN nominal compounds implies access to the representation of their constituents. Although facilitation appeared to emerge when either the head or the modifier were primed (suggesting that both constituents are accessed during compound processing), the mixed-effect analysis revealed that the priming effect is modulated by the constituent properties (position and/or headedness) in head-final compounds: there is a larger priming effect for this type of stimuli when the second constituent is primed, suggesting that the mental representation of head-final compounds is organized along an internal hierarchy, in line with the second constituent effect found in English (Libben et al. 2003, Juhasz et al., 2003). However, it is still unclear whether this “privileged status” of the second constituent depends on its position: in fact, the second constituent of these compounds is also the morphological head as it shares its grammatical properties with the whole construct; therefore, the greater facilitation obtained by priming this constituent can be accounted for by the strength of the link between the representation of the head constituent and that of the entire compound. The results obtained for head-initial compounds may be of help in this respect: if the head plays the primary role in compound processing, stronger facilitation is to be expected when the first constituent is primed; on the contrary, if the second constituent effect is a result of its final position, a greater second-constituent facilitation would be expected in head-initial Italian compounds. Surprisingly, neither the first nor the second constituent generated greater priming effect in head-initial compounds. This may indicate that the mental representation of head-initial compounds is equally tied to both constituents (i.e., flat representation, see Di Sciullo & Williams 1987), while head-final compounds have a stronger link with their second (head) constituent (i.e., hierarchical representation). In this framework the constituents of head-initial compounds are equally important in achieving compound recognition, while in head-final compounds the head serves as a preferential access code to the whole compound. However, these results may also point to an advantage of the second constituent AND a privileged role of the morphological head: if headedness and second-position interact in this way a greater second-constituent faciliation should be expected in head-final compounds, and equal priming in head-initial compounds. These alternative hypotheses will be disentangled in the next experiment.

Experiment 2: the Processing of Verb-Noun compounds

One possible way of disentangling the two explanations raised in Experiment 1 is to test positional and head effect independently; this can be done with Italian verb-noun (VN) nominal compounds as they are exocentric, i.e., neither constituent is the morphological head. In fact, VN Italian compounds are invariably nouns, hence the verbal constituent is not the head. Moreover, in these compounds, the nominal constituent is almost always the object of the verbal constituent, and is not the head because it does not fulfil the semantic criterion; for instance, *lava*$_V$*stoviglie*$_N$ ('dishwasher', lit. 'washes'-'dishes') is not a kind of dish. The head is therefore an implied element, external to the compound itself (see Dressler, 2006).

Italian VN compounds can be very useful in evaluating positional effects and in testing the flat-representation hypothesis proposed for head-initial compounds. Very specific predictions can in fact be made regarding their constituent priming, which may shed light on the issues raised by the results of Experiment 1. Since neither of the two constituents is the morphological head, position effect can be tested independently from headedness. If the greater facilitation that emerged in Experiment 1 (when the second constituent of head-final NN compounds was primed) is due to a position effect, the same result is to be expected in VN compounds. If, on the contrary, head-final NN compounds received greater facilitation from their second constituent because of a headedness effect, it is to be expected that VN compounds will receive the same facilitation from the two constituents, as neither is the morphological head.

Materials and Methods

Participants.

Thirty-two Milano-Bicocca University undergraduates and graduates participated in this experiment (5 males and 27 females, mean age = 23±3, mean education = 18±3). All were native Italian speakers with normal or corrected-to-normal vision and no reading disorders; they participated in the study in exchange for practical credits or as volunteers.

Materials.

Twenty-four Italian VN nominal compounds (e.g., *guardaroba*, 'closet', lit. 'look'+'stuff') were selected as targets. Each of the 24 VN compounds was paired with four different primes: (1) the first constituent (*guarda/GUARDAROBA* – 'look'/'CLOSET'); (2) the second constituent (*roba/GUARDAROBA* – 'stuff'/'CLOSET'); (3) a control word for the first constituent (*guasta/GUARDAROBA* – 'waste'/'CLOSET'); (4) a control word for the second constituent (*rosa/GUARDAROBA* – 'rose'/'CLOSET'). Control words were semantically unrelated to the compound as a whole and to either of its constituents; moreover, they were orthographically and phonologically very similar to the corresponding constituent primes (mean number of shared letters in the same position was 70%). Constituent primes and control words were matched for lemma frequency, form frequency, length and neighbourhood size. Finally, control primes were words of the same grammatical class as the corresponding constituents.

As in Experiment 1, 24 VN pseudo-compounds were created as targets for the nonword trials (e.g., *leggigrano,* lit. ‘read-corn’). 50% of the target compounds were primed by the first constituent and the remaining 50% was primed by the second constituent.

To avoid any strategic effect caused by the experimental set being formed exclusively by morphologically complex stimuli, 24 mono-morphemic filler trials were included in the experiment; in these trials the targets were twelve non-words (obtained by changing one or two letters in existing words) and twelve real words. Each filler target was primed by a real word.

Procedure and trial structure.

The procedure used was the same as that of Experiment 1, the only difference being that all 24 trials were administered in a single block.

Data analysis.

Inverse RTs and response accuracy were analyzed employing mixed effects models. The RT analysis was performed on correct responses only. Responses with particularly long latencies (defined as two or more SD from RT mean by participant) or with times faster than 300 ms were considered to be outliers and were excluded from the analysis. Two factors were manipulated, i.e., Prime Type and Primed Constituent (see Table 1).

Results

(INSERT FIGURE 3 ABOUT HERE)

Figure 3 summarizes the descriptive statistics for RTs in the different experimental conditions. A mixed effects analysis was also carried out, with participants and items as crossed random effects (Baayen, et al., 2008). PT and PC were modelled as fixed effects. The analysis started from a full factorial model, which was simplified following the procedure employed in the first experiment (see above and Appendix A). The final model included PT as a fixed effect, a random effect of participants on PT and on the intercept and a random effect of items on the intercept.

(INSERT TABLE 3 ABOUT HERE)

The estimated parameters of the final model are summarized in Table 3. The effect of PT was found to be significant. The model indicates an overall priming effect of about 60 ms, and no significant interactions.

(INSERT FIGURE 4 ABOUT HERE)

Table 5 illustrates the descriptive statistics for accuracy. A mixed effects model was obtained employing the same procedure as above. The final model included PT and PC as fixed effects and item and participants as random effects on the intercept. A significant PT effect was found (estimated parameter 1.40, z=4.17, p<.001), confirming the findings resulting from the RT analysis: the degree of accuracy of the lexical decision on a VN nominal compound primed by one of its constituents was significantly higher than when the compound was primed by a control word.

Discussion

The results obtained from the second experiment also support morphological parsing of nominal compounds. The priming effects were not modulated by the position of the primed constituent: in other words, the verb-constituent and the noun-constituent were equally efficient in priming the target compound. As the compounds used in this experiment were exocentric (i.e., neither constituent was the morphological head of the compound), the symmetric priming elicited by the first and the second constituent did not support a position effect in processing Italian compounds: the results suggest representation without a salient role for both the first and the second constituent, even if the verb-constituent of a VN nominal compound clearly takes the second constituent as argument topic from a syntactic point of view. Therefore the data resulting from this experiment support the hypothesis that VN compounds are processed with the same procedure as head-initial compounds.

General Discussion

Two priming experiments were carried out to explore the mental processing of compound words and to disentangle the effects of headedness and constituent position. The Italian language, whose vocabulary contains both head-initial and head-final compounds, is ideal for testing internal hierarchy of compounds.

In the first experiment, endocentric compounds (i.e., compounds with an internal head) were studied with a priming paradigm. Results showed that the parent compound is primed by both constituents, suggesting routine decompositional processing of endocentric compounds. However, data for head-initial and head-final compounds differ significantly; while the priming effect of the first and second constituents does not differ for head-initial compounds, head-final compounds show a greater priming effect for the head-constituent than for the modifier. In the second experiment, Italian VN compounds were investigated with the same experimental paradigm; these compounds are particularly relevant to the issue as they do not have an internal head and therefore it is possible to test the role of position in constituent priming without it being confounded with headedness. The effect of constituent priming in Italian VN does not vary according to the position of the primed constituent.

In the first place, this study has shown that constituent priming arises both in endocentric (Experiment 1) and exocentric compounds (Experiment 2). These results are in line with those obtained in several previous studies (e.g., Jarema et al., 1999; Libben et al., 2003) and strongly suggest that constituent representation is accessed during the processing of compound nouns. However, this result does not necessarily rule out whole-word access: indeed, a parallel study using the same material (Marelli & Luzzatti, submitted) indicates that global representations are also accessed during compound processing.

However, the main objective of this study was to clarify the relationship between the effects of position and headedness in constituent priming; the Italian language provides a suitable platform for experiments of this type as its endocentric compounds are either head-initial or head-final, while English and Dutch only have head-final compounds.

Previous evidence obtained in French (Jarema et al., 1999), pointed to interaction between an advantage for the first constituent (arguably because of left-to-right processing) and a privileged role of the morphological head. The results obtained in Experiment 1 did not confirm this hypothesis; if the headedness and position interaction suggested by Jarema et al. were present in Italian, then a first-constituent advantage in head-initial compounds greater than a second-constituent advantage in head-final compounds was to be expected. On the contrary, however, Experiment 1 showed that while head-initial compounds do not show different priming effects for the first and second constituents, head-final compounds show a larger priming effect for the head-constituent than for the modifier. Therefore, the mental representation of head-initial compounds would appear to be tied equally to both individual constituents, while head-final compounds are more strongly linked to the second (head) constituent. The results of Experiment 2 were in line with this hypothesis, as no different priming effects appeared for either the first or the second constituent. This can be easily interpreted by suggesting that exocentric VN compounds have an internal representation that is analogous to that of endocentric head-initial compounds, i.e., the mental representation of the two constituents is tied equally to the representation of the whole compound.

How is this asymmetrical representation for head-initial and head-final compounds to be justified? Williams (1981) claimed a right-headedness rule for all morphologically complex words (right-hand head rule, RHR). The possibility of generalizing this assumption from strictly right-headed languages as English and Dutch to Romance languages has been debated. Di Sciullo and Williams (1987) proposed that in these latter languages both head-initial compounds and VN compounds are “syntactic words”, i.e., syntactic strings imported into the lexicon, a juxtaposition of words without a real morphological hierarchy. According to the results of the present study, these linguistic properties could be reflected in the organization of the mental lexicon: indeed the observed priming-effect pattern for head-final compounds suggests an underlying internal hierarchy; on the contrary, neither head-initial compounds nor VN compounds elicit different performances when priming the head or the modifier, i.e., they have a flat representation.

As the head lemma contains the information regarding grammatical class and, for nouns, grammatical gender (Levelt, Roelofs & Meyer, 1997), it should play a crucial role in the mental processing of complex words. However, in Italian, head-final words are much more common than head-initial words: i) diachronically, Neo-Latin compounds are head-initial (Scalise, 1994) but head-final compounding is increasingly present in contemporary Italian (Schwarze, 2005); ii) derived words are always head-final, the suffix being the morphological head as a rule. Therefore the assumption of right-headedness as the default morphological mental structure is in line with the distributional properties of Italian lexical morphology. The hypothesis of an internal hierarchy for head-final compounds only in Italian is in line with previous results: head-final compounds were found to elicit a larger P300 component (indicating working-memory activity) than head-initial compounds (El Yagoubi et al., 2008). This evidence may indicate a contextual updating, as proposed by the Authors, but may also be due to processing for head-final, morphologically complex compounds being more demanding than for head-initial, flat-represented compounds.

As anticipated above, studies carried out in other Romance languages (see Jarema et al., 1999 for French) yielded different results, which led to the hypothesis of an interaction between head- and first-position effects. On the contrary, the results obtained from the experiments conducted in the present study are best summarized as a head-final effect, thus suggesting cross-linguistic differences in the mental representation of compounds, even between closely related languages. Head-final compounding is indeed less productive in French than in Italian (Schwarze, 2005). This difference would lead to different compound processing in the two languages: French head-initial compounds are relatively more frequent than head-finals, and thus more likely to be processed as hierarchical structure than they would be in Italian.

However, the results of the present study could be interpreted in a different manner. Indeed, the 30ms first-constituent priming on head-final compounds, which emerged in Experiment 1, was quite odd, since equally larger priming effects were found in the other three conditions. Moreover, VN compounds also yielded large priming effects (50-60ms). The question therefore is why priming the modifier of head-final compounds produces such different results. Although they are exocentric, VN compounds have an internal syntactic structure: as they are similar to verb-phrases, it can be argued that the verb is the most important constituent. Even from a semantic point of view, the verb is the most important element for interpreting the meaning of a VN compound: as in the case of English synthetic compounds, a *lavapiatti* (*dishwasher*, lit. *wash-dishes*) is something that washes, i.e., a washer. Therefore, it is the verb that specifies the superordinate category of which the whole compound specifies a subordinate subcategory, as do the head of endocentric compounds. Since VN compounds are more common than NN compounds in Italian, a native reader would be justified in expecting the first constituent to be the semantic head. When that expectation is not met (i.e., in the case of head final compounds), the prime is mistakenly interpreted as the head, leading to a reduced priming effect. This interpretation fits our results equally well, and shall be investigated in future studies.

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Appendix A

The mixed-effects model analyses were conducted with the open-source statistical program R (R Development Core Team, 2008), freely available on the Internet at http://cran.r-project.org/. In particular, two R packages were used ('lme4': Bates, 2005; 'languageR': Baayen, 2008), which contain a number of pre-compiled functions needed to fit and analyse mixed-effect models; these packages are also freely available on-line at http://cran.r-project.org/. For more specific instructions on how to install and use R packages and for any other details regarding statistical analyses with R, the reader is referred to Crawley (2007) or to any of the introductory articles provided on the R website (e.g., Venables, Smith & R Development Core Team, 2009). With regards the mixed-effect model analyses, a clear and complete introduction to this technique is provided in Baayen (2008),in Baayen, Davidson and Bates (2008) and in Jaeger (2008).

The following pages provide a report on the analyses performed on RTs for the NN compounds (experiment 1). Details are given only for RT analysis in Experiment 1 as the same procedure was used also for the subsequent analyses.

As reported in the corpus of the paper, the analyses started from a full-factorial model with headedness (H), Primed Constituent (PC) and Prime Type (PT) as fixed effects (see Table 1) for the specification of the dichotomic coding), and random intercepts for both participants and items. The R code for fitting such a model is the following:

```
model1 <- lmer((-1000/RT) ~ H*PC*PT + (1|subj) + (1|item),
data=exp1, REML=FALSE)
```

We fitted -1000/RT in preference to RT because the former measure has a more Gaussian-like distribution which increases the statistical power of the analysis (van Zandt, 2002).

A first inspection of the model clearly indicated that several fixed effects did not contribute significantly to the overall goodness of fit of the model:

```
> model1
Linear mixed model fit by maximum likelihood
Formula: (-1000/RT) ~ PT * PC * H + (1 | item) + (1 | subj)
Data: exp1
   AIC   BIC logLik deviance REMLdev
 4.982 61.74   8.51   -17.02   27.16
Random effects:
 Groups   Name        Variance Std.Dev.
 item     (Intercept) 0.013248 0.11510
 subj     (Intercept) 0.034134 0.18475
 Residual             0.049246 0.22191
Number of obs: 1287, groups: item, 48; subj, 32

Fixed effects:
            Estimate Std. Error t value
(Intercept) -1.38584    0.04417 -31.376
PT          -0.14413    0.02491  -5.787
PC          -0.04175    0.02575  -1.621
H           -0.04544    0.04228  -1.075
PT:PC        0.03247    0.03529   0.920
PT:H         0.06068    0.03560   1.705
PC:H         0.04953    0.03656   1.355
PT:PC:H     -0.09649    0.05012  -1.925
```

This is revealed by the fact that a number of *t* values (reported in the last column to the right of the fixed-effects section) are quite low (without taking sign into consideration). The function lmer does not calculate the probability associated with these *t* values; however, fixed effect with *t* values lower than 1 are not significant and very unlikely to give any relevant contribution to the fit of the model. Therefore, as reported in the corpus of the paper, $|t| < 1.0$ was adopted as the exclusion criterion. This threshold is in fact quite arbitrary: a tougher criterion of, say, $|t| < 1.5$ would have been quite legitimate and probably would have led to a more parsimonious model. However, the criterion adopted guaranteed that no significant contribution from individual fixed effects would be missed. Applying this criterion, the second-level interaction between PC and PT was then removed from the model:

```
> model2 <- lmer((-1000/RT) ~ H + PC + PT + H:PC
+ H:PT + H:PC:PT + (1|subj) + (1|item),
data=exp1, REML=FALSE)
```

A check was then run to verify whether the elimination of this effect would impact significantly on the overall goodness of fit:

```
> anova(model1,model2)
Models:
model2: (-1000/RT) ~ PT * H + PC * H + PT:PC:H +
         (1 | item) + (1 | subj)
model1: (-1000/RT) ~ PT * PC * H + (1 | item) + (1 | subj)
       Df    AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
model2 10  3.828 55.429  8.086
model1 11  4.982 61.742  8.509 0.8465      1     0.3576
```

Since Pr(>Chisq) was higher than .05, this appeared not to be the case.

Effects with |t|<1.00 were removed until Model 5, which did not include any effect whose |t| was lower than 1, was reached.

```
> model5
Linear mixed model fit by maximum likelihood
Formula: (-1000/RT) ~ PT + PT:H + PT:PC:H + (1 | item) + (1 | subj)
    AIC   BIC logLik deviance REMLdev
 0.1348 36.26  6.933   -13.87   9.051
Random effects:
 Groups   Name        Variance Std.Dev.
 item     (Intercept) 0.013369 0.11563
 subj     (Intercept) 0.034117 0.18471
 Residual             0.049359 0.22217
Number of obs: 1287, groups: item, 48; subj, 32

Fixed effects:
            Estimate Std. Error t value
(Intercept) -1.41692    0.03782  -37.46
PT          -0.12569    0.01711   -7.34
PT:H         0.03590    0.02650    1.35
PT:H:PC     -0.05645    0.02432   -2.32
```

Therefore, this was considered to be the best fixed-effect structure.

The random effect structure was then analyzed to check whether adding random slopes improved the fit of the model. A model with a random slope includes a “correction” – specific for each participant or each item – to the estimated size of a fixed effect. For example, the estimated parameter for the first-level PT effect (the overall priming effect) is currently -0.1256, representing the difference in -1000/RT between related and unrelated trials. This parameter referred to the overall mean of items and participants; however, it seems reasonable to assume that participants may differ in their general sensitivity to priming effects, so that the overall difference between related and unrelated trials may vary across participants (a similar consideration can be drawn for items). The introduction of random slopes basically accounted for this variation, thus reducing the total amount of unexplained variance, which in turn allowed a more precise significance test on the fixed effects. Rather than reporting each single step of the random effect analyses, the two random slopes added to the final model which determined a significant improvement in the overall fit are illustrated. At this stage, models were fitted employing REML=TRUE (relativized maximum likelihood) to get optimal estimates for both fixed and random effects.

A by-participant adjustment turned out to be necessary to estimate the overall priming effect, i.e., a by-participant random slope on the first-level PT effect was added to the model:

```
> model5T.1 <- lmer((-1000/RT) ~ PT + H:PT + H:PC:PT +
(1 + PT|subj) + (1|item), data=exp1, REML=TRUE)
```

```
> anova(model5T,model5T.1)
Data: exp1
Models:
model5T: (-1000/RT) ~ PT + PT:H + PT:PC:H + (1 | item) + (1 | subj)
model5T.1: (-1000/RT) ~ PT + PT:H + PT:PC:H +
            (1 | item) + (1 + PT | subj)
          Df    AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
model5T    7  0.144 36.264  6.928
model5T.1  9 -8.022 38.419 13.011 12.166      2   0.002282 **
```

In addition, the capacity of the model to explain the data benefited from a by-item random slope on the third-level interaction between H, PC and PT:

```
> model5T.2 <- lmer((-1000/RT) ~ PT + H:PT + H:PC:PT +
(1 + PT|subj) + (1 + H:PC:PT |item), data=exp1, REML=TRUE)

Data:
Models:
model5T.1: (-1000/RT) ~ PT + PT:H + PT:PC:H +
           (1 | item) + (1 + PT | subj)
model5T.2: (-1000/RT) ~ PT + PT:H + PT:PC:H +
           (1 + PT:PC:H | item) + (1 + PT | subj)
          Df     AIC     BIC  logLik  Chisq Chi Df Pr(>Chisq)
model5T.1  9  -8.022  38.419  13.011
model5T.2 11 -13.484  43.276  17.742 9.4622      2   0.008817 **
```

No other by-participant or by-item correction determined a general improvement in the overall goodness of fit of the model. The parameters estimated by Model 5T.2 are given below, together with the general model statistics:

```
> model5T.2
Linear mixed model fit by REML
Formula: (-1000/RT) ~ PT + PT:H + PT:PC:H
+ (1 + PT:PC:H | item) + (1 + PT | subj)
   AIC   BIC logLik deviance REMLdev
 8.521 65.28   6.74   -35.48  -13.48
Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 item     (Intercept) 0.0151033 0.122896
          PT:PC:H     0.0108343 0.104088 -0.622
 subj     (Intercept) 0.0271321 0.164718
          PT          0.0037863 0.061533 0.609
 Residual             0.0475976 0.218169
Number of obs: 1287, groups: item, 48; subj, 32

Fixed effects:
            Estimate Std. Error t value
(Intercept) -1.41665    0.03530  -40.13
PT          -0.12353    0.02010   -6.15
PT:H         0.03589    0.02625    1.37
PT:H:PC     -0.06478    0.03096   -2.09
```

The residuals of the model were not correlated to the predicted values:

```
> cor(fitted(model5T.2),residuals(model5T.2))
[1] 0.07571544
```

Finally, we ascertained that the results of the analysis were not driven by a few overly influential outliers. This was done by plotting four scatterplots (one for each combination of the H and PC factors) where each point represents a specific item and its coordinates are given by the mean response time obtained by subjects on that item in the related (X axis) or unrelated (Y axis) condition (see Figure A). In these graphs, points (items) lying above the diagonal indicate facilitation; their X-coordinate (the mean RT on related trials) is in fact smaller than their Y-coordinate (the mean RT on unrelated trials). Points lying below the diagonal indicate instead inhibition, as their X-coordinate (the mean RT on related trials) is larger than their Y-coordinate (the mean RT on unrelated trials).

(INSERT FIGURE A ABOUT HERE)

The charts in the upper panels clearly show that there is strong constituent priming in head-initial compounds, as virtually all points (with the exception of two outliers in the upper right-hand graph) cloud above the diagonal; similar conclusions can be drawn from the lower right-hand chart (head-final compounds, priming on the second constituent), even though a limited number of items do show some inhibition or no effect. On the contrary, points are fairly equally distributed above and below the diagonal in the lower left-hand graph, thus indicating that the priming effect (if there is any) is strongly attenuated in this condition (head-final compounds, priming on the first constituent). This fully reflects the results of the analyses reported above. These graphs clearly indicate that results are not driven by a few influential outliers: with the exception of three items in the upper left-hand chart and three items in the upper right-hand chart points cloud quite consistently in all charts.

TABLES

TABLE 1:

Experiment 1 - Variables considered and their levels

Variables	Reference levels (coded as 0)	Contrasting levels (coded as 1)
Prime type (PT)	Control word: *peste* primes *pescespada* *sposa* primes *pescespada*	Constituent: *pesce* primes *pescespada* *spada* primes *pescespada*
Primed constituent (PC)	1st constituent: *pesce* primes *pescespada* *peste* primes *pescespada*	2nd constituent: *spada* primes *pescespada* *sposa* primes *pescespada*
Headedness (H)	Head-initial: *pescespada*	Head-final: *astronave*

TABLE 2:

Experiment 1, Mixed-effect analysis. Parameters estimated by the final model and their statistical significance analysis. The last column on the right reports the parameters estimated by the same model applied to the untransformed RTs.

Effects	Estimated parameters (-1000/RT)	Std. error	*t* (df = 1284)	*p*	Estimated parameters (RT)
Intercept	-1.4167	.035	40.13	<.001	733
PT	-.1235	.020	6.15	<.001	-53
PT by H	.0359	.026	1.37	.17	19
PT by PP by H	-.0648	.031	2.09	<.05	-28

TABLE 3:

Experiment 2, Mixed-effect analysis. Parameters estimated by the final model and their statistical significance analysis. The last column on the right reports the parameters estimated by the same model applied to the untransformed RTs.

Effects	Estimated parameters (-1000/RT)	Std. error	*t* (df = 643)	p	Estimated parameters (RT)
Intercept	-1.3933	.041	33.87	<.001	750
PT	-.1262	024	5.16	<.001	-60

FIGURE CAPTIONS

Figure 1: Priming Effect (PE) on response times for the first and second constituents in head-initial and head-final compounds

Figure 2: Priming Effect (PE) on accuracy for the first and second constituents in head-initial and head-final compounds

Figure 3: Priming Effect (PE) on response times for the first and second constituents in verb-noun compounds

Figure 4: Priming Effect (PE) on accuracy for the first and second constituents in verb-noun compounds

Figure A: Mean RTs on items in the related (X axis) or unrelated (Y axis) condition; each scatterplot represents a combination of the factors Headedness and Primed Constituent factors.

FIGURE 1

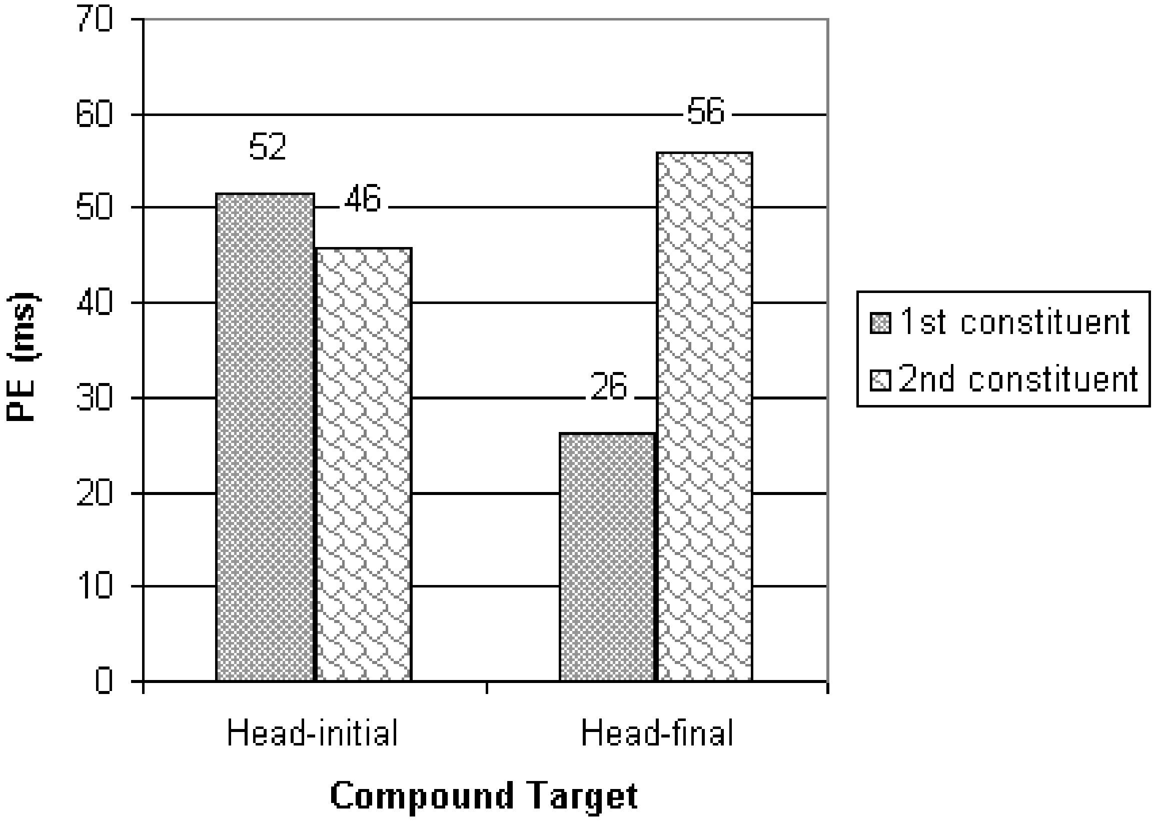
70
60
50
40
30
20
10
0
PE (ms)
52
46
26
56
Head-initial
Head-final
Compound Target
1st constituent
2nd constituent

FIGURE 2

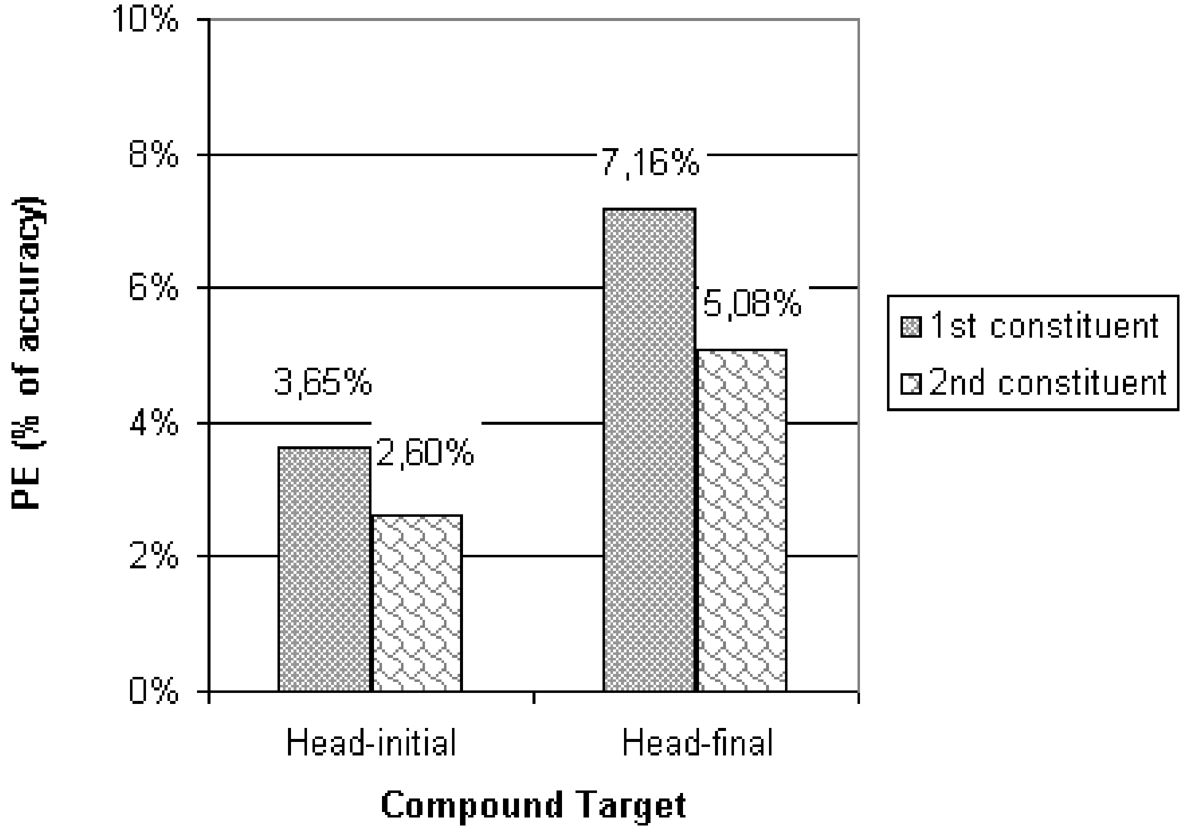
10%
8%
6%
4%
2%
0%
PE (% of accuracy)
3,65%
2,60%
7,16%
5,08%
Head-initial
Head-final
Compound Target
▨ 1st constituent
▨ 2nd constituent

FIGURE 3

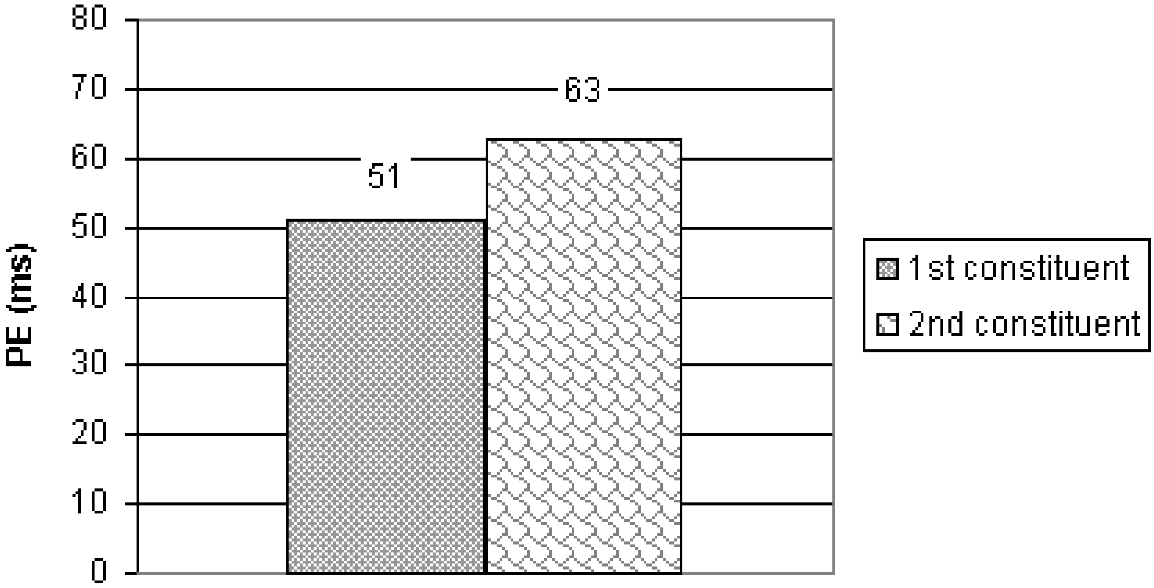
PE (ms)
0
10
20
30
40
50
60
70
80
51
63
1st constituent
2nd constituent

FIGURE 4

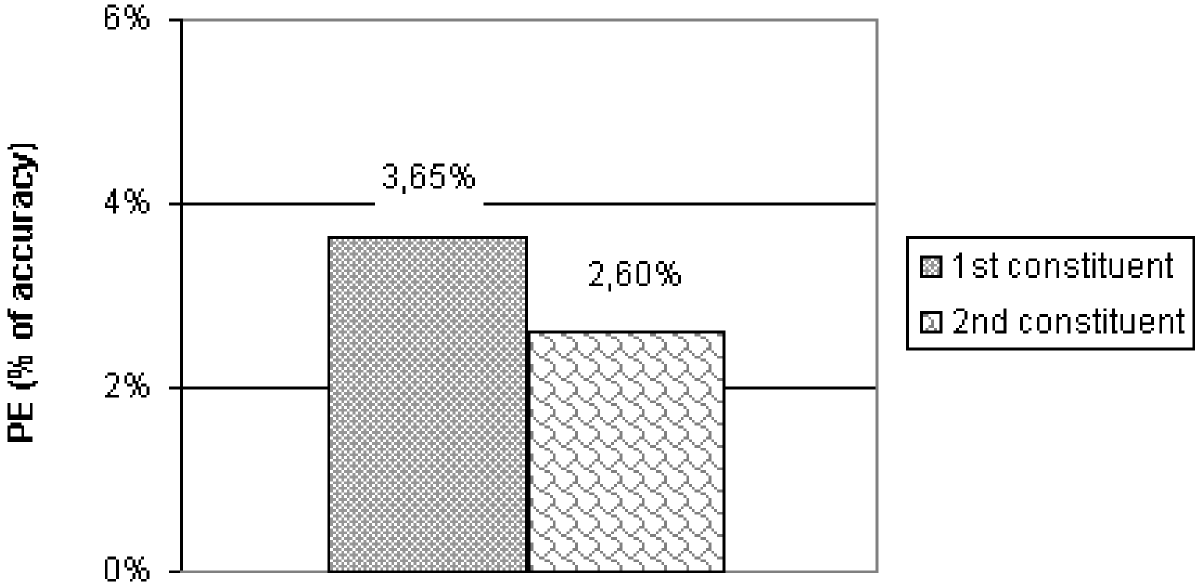
6%
4%
2%
0%
PE (% of accuracy)
3,65%
2,60%
1st constituent
2nd constituent

FIGURE A (Appendix)