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The mental representation of compound nouns: evidence from neuro- and psycholinguistic studies

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Abstract

There is a general debate as to whether constituent representations are accessed in compound processing, and which compound properties (e.g., headedness, semantic transparency) would influence this parsing procedure. This thesis investigates the mental representation of compound nouns in a series of six studies exploiting the properties of the Italian language, in the fields of both psycholinguistics and cognitive neuropsychology.

First, effects related to the compound structure were investigated in the context of neglect dyslexia (Chapter 1). Second, converging evidence in favor of the headedness effect was sought in a constituent-priming experiment on normal participants (Chapter 2) and through the assessment of compound naming errors in patients suffering from aphasia (Chapter 3). Third, the access to grammatical properties of the constituents was studied in a single case study on deep dyslexia (Chapter 4). Fourth, the role of compound semantic transparency was investigated by assessing constituent frequency effects in both lexical decision latencies (Chapter 5) and fixation durations during compound-word reading (Chapter 6).

The results indicate that the variables related to the whole compound (i.e., compound headedness, whole-word frequency and semantic transparency) play a crucial role in word processing, but also that constituent representations are accessed. To explain the observed effects a model will be proposed, positing both a multiple-lemma representation of compound words and a parallel procedure dedicated to the conceptual combination of compound constituents.

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Introduction:

The processing of compound words in the psycholinguistic and neurolinguistic literature.

Processing models of morphologically complex words

Compounds are morphologically complex words made of two (or more) existing words. These constituents are typically free-form morphemes, i.e., as opposed to affixes, they can stand alone in a sentence. Whether complex words in general and compounds in particular are represented in the mental lexicon is the subject of lengthy debate. Is a morphologically complex word accessed as a whole or rather built on line through its morphological constituents?

Both full-listing and full-parsing models have been proposed in the field of visual word-recognition. The full-listing hypotheses (e.g., Butterworth, 1983) conceive a separate lexical entry for each single inflected, derived or compound word-form. On the contrary, in the full-parsing model framework (Taft & Forster, 1975; Rastle, Davis & New, 2004), an automatic parsing procedure leads to the access to the constituent morphemes of morphologically complex words.

However, neither of these solutions is completely supported by empirical data and mid-way models have been proposed, in which both whole-word and parsing processing are employed during lexical access. Which mechanisms govern this processing, as well as the exact sequencing of its steps, is still debated. According to the dual-route model of visual word recognition (Schreuder & Baayen, 1995; Pollatsek, Hyönä & Bertram, 2000), parsing and direct access of morphologically complex words are parallel processing routes, their efficiency being governed by frequency effects: high frequency word forms are easier to access as whole words, while low-frequency word forms containing frequent morphemes are likely to be segmented. The multiple route, interactive model of reading recently proposed by Kuperman, Schreuder, Bertram, & Baayen (2009) can be considered as an evolution of dual route models in the light of the maximization-of-opportunity theory (Libben, 2006). The model assumes early simultaneous access to multiple sources of information and multiple processing mechanisms in complex word recognition. However, alternatively to parallel route accounts, morphologically complex words could be sequentially accessed, with processing starting with whole-word representation followed by access to the morpheme representations (e.g., the supra-lexical model: Giraudo & Grainger, 2001).

These models have been proposed mainly to explain written word input processing, but the issue is also debated in the literature on word production (e.g., Janssen, Bi & Caramazza, 2008): in this context, the question is whether compounds are retrieved as a unique representation (e.g., Caramazza, 1997), or whether their constituents are assembled on line (e.g., Levelt, Roelofs & Meyer, 1999). In fact, dual-route models have also been proposed to explain complex word production (e.g., Luzzatti, Mondini & Semenza, 2001).

A promising approach would be to consider complex word representation as part of a lexeme-lemma architecture (Levelt et al., 1999). This influential model posits two separate levels of lexical processing. At the lexeme level phonological forms of morphemes are stored independently, while abstract representations of words containing syntactic and semantic information are stored at the lemma level. Different word forms at lexeme level (e.g., *run*, *run+s*, *ran, run+ing*) are thought to converge on a unique lemma node since they share the same lexical properties. How compound words are represented in this model, however, is somewhat more complex. Since a compound has properties (e.g., grammatical class, lexical gender) that are not necessarily related to its constituents, one possibility is to consider the compound structure to be represented as an independent lemma node; this can activate stored constituent representations at the lexeme level separately (Mondini, Luzzatti, Zonca, Pistarini & Semenza, 2004). According to this approach, the compound lemma node would be virtually indistinguishable from a representation of the compound structure, as described by Semenza. Luzzatti & Carabelli (1997) in naming tasks, and by Rastle, Tyler, & Marslen-Wilson (2006) in reading tasks; in fact, the compound lemma node would contain the lexical-syntactic properties of the compound and the information regarding which phonological units enter the compound word. The activation of the constituent lexemes could be also mediated by the constituent lemma nodes. In fact, as in the multiple-lemma case described by Levelt at al. (1999), a complex-word concept may activate multiple nodes in the lemma system; in other words, not only would the syntactic properties of the whole word be retrieved, but also the characteristics of the constituent morphemes would become active. This would also be in line with the model proposed by Sprenger, Levelt, & Kempen (2006), regarding the production of idiomatic forms. These lexical combinations are similar to compounds in so far as they are formed by several lexical items which have their own lemma representations. In Sprenger et al.'s proposal idiomatic forms are represented as "superlemmas", a particular unit which would store information about the syntactic constraints of the idiom, and delimit the syntactic properties of the simple lemmas in the compound.

Compound processing in the psycholinguistic research

Although any compound word could be theoretically accessed through a whole-word representation in the mental lexicon (e.g., Butterworth, 1983), converging evidence from different methodologies testifies against this hypothesis, indicating rather that compounds are parsed into their constituents during processing. Taft & Forster (1976) ran a lexical decision experiment employing false compounds formed by two existing words (*dustworth*), two non-words (*mowdflisk*) and a word plus a non-word (*footmilge, trowbreak*). They found that false compounds were indicated more rapidly as non-existent when a non-word (*truwbreak, mowdflisk*) formed the first constituent as opposed to a word (*dustworth, footmilge*). This evidence led the authors to conclude that complex words are routinely decomposed and that the first constituent serves as lexical access-code for the whole word, due to a left-to-right process.

Subsequent studies, however, did not completely confirm this hypothesis: while they clearly indicated a parsing process, they also revealed an important role of the second constituent. A number of studies (Zwitserlood, 1994; Jarema, Busson, Nikolova, Tsapkini & Libben, 1999; Kehayia, Jarema, Tsapkini, Perlak, Ralli & Kadzielawa, 1999; Libben, Gibson, Yoon & Sandra, 2003) have employed the constituent priming paradigm, in which the presentation of a target compound (e.g., *bedroom*) is preceded by the presentation of one of its constituents (e.g., *room*). The prior presentation of one or the other constituent significantly speeds up the response time to compounds in several languages, thus suggesting that both constituents can facilitate compound access and are therefore both accessed during compound processing. Eye-tracking studies on compound reading lead to a similar conclusion, since the frequency of both constituents modulates the pattern of fixations on the compound targets (Lima & Pollatsek, 1983; Andrews, Miller & Rayner, 2004). Moreover, access to constituent representations seems to take place at a very early processing level: the same effect can also be found under a masked priming paradigm (Forster & Davis, 1984), which is traditionally considered to tap into the initial stages of word processing. In this paradigm the prime is not explicitly perceivable, making it an ideal condition for investigating lexical access, ruling out any conscious appreciation of the relationship between prime and target. Shoolman & Andrews (2003) found a similar priming effect with both the first- and the second-constituent prime, indicating that both constituents are equally efficient at pre-activating compound representation. Their conclusion is strengthened by the results of a study in Basque by Duñabeitia, Laka, Perea & Carreiras (2009): in this study primes were compound words sharing either the first (e.g., *milkshake*) or the second (e.g., *postman*) constituent with the compound target (e.g., *milkman*). The authors found that the two constituents had similar priming effects, independent of their position in the string and of spatial congruency in prime and target (e.g., *boathouse* is primed by both *housewife* and *farmhouse*). These results strongly indicate that i) compounds are parsed during processing and that ii) constituent activation leads to an automatic and position-independent facilitation process on compound access.

However, this evidence is in contrast with other results indicating sequential access to constituents during compound processing (e.g., Hyönä, Bertram & Pollatsek, 2004; Juhasz, Pollatsek, Hyönä & Rayner, 2009; Drieghe, Pollatsek, Juhasz & Rayner, 2010). Moreover, the effects of the first- and second-constituents are not always equal. In a multiple-task study (lexical decision, naming and eye-fixation analysis) on English compounds, Juhasz, Starr, Inhoff & Placke (2003) found that the frequency effect of the second constituent was significant in all tasks, while the frequency effect of the first constituent only influenced the performance in the naming task. This suggests a predominant role of the second constituent in accessing the whole compound, which is in contrast with Taft & Forster's (1976) results and hypothesis. The second-constituent effect was replicated by Pollatsek et al. (2000) in an eye-tracking study in Finnish. In their experiments, the authors manipulated the frequencies of both the second-constituent and the whole-word, demonstrating that both measures significantly influence gaze duration, and thus are both implicated in compound access. Whole-word frequency also had a mild influence on the duration of the first fixation, but Hyönä & Pollatsek (1998) had already demonstrated that first-fixation duration is mainly modulated by the frequency of the first constituent. Therefore the first constituent is accessed, and its effect arises, at an earlier level of processing. All these results are in line with a dual-route model of lexical access (Schreuder & Baayen, 1995), according to which the representation of a complex word can be accessed both as a whole and through its individual morphemes by a parsing procedure. The parsing route conceives a sequential access to constituents, the first constituent being accessed earlier given the left-to-right procedure (Pollatsek et al., 2000). But why, then, is the second constituent equally important (if not more so, see Juhasz et al., 2003) in compound access? Since both in English and Finnish the second element is the head constituent, and thus conceptually related to the whole compound (but see Inhoff, Starr, Solomon & Placke, 2008), its effect would arise while accessing the meaning of the compound, in line with the results indicating a later effect of the final constituent (Juhasz et al. 2003).

However, the role of headedness in compound access has yet to be clarified. First, it should be noted that studies on English (and other Germanic languages) and Finnish have been unable to disentangle the effect of the head constituent and a purely positional effect since the head is always the second constituent (Williams, 1981). Therefore Romance languages, which offer both head-initial and head-final compounds, should be employed to test the headedness effect. Second, the head does not always carry important semantic information: Inhoff et al. (2008) showed that the conceptual relationship of the modifier to the compound meaning can be stronger than that of the head, and that the meaning-carrier constituent, regardless of its position, manifests an important frequency effect in different tasks (lexical decision, word naming and sentence reading). Once its semantic superiority has been ruled out, the head constituent is important because it shares its morpho-syntactic properties (i.e., grammatical class and grammatical gender) with the whole compound. This is quite clear in Italian: for example, the head of the compound noun *pescespada* (*swordfish*, lit. *fish+sword*) is *pesce* not only because the *pescespada* is a *pesce (fish)*, but also because *pesce* and *pescespada* are masculine, while *spada* is feminine: i.e., the constituent *pesce* percolates its grammatical gender to the whole compound.

To my knowledge, only two psycholinguistic-studies have tried to disentangle the role of headedness from a second-position effect. Duñabeitia, Perea & Carreiras (2007) compared constituent frequency effects in Basque and Spanish, and found that the second-constituent frequency has a similar effect on lexical-decision response times. Since Spanish compounds are mainly head-final, and Basque compounds are mainly head-initial, the authors concluded in favor of a second position effect with no headedness effect. Albeit cross-linguistic comparisons are fundamental when investigating the present issue, a direct, within-language manipulation of the headedness variable is necessary to test a potential headedness effect. In the constituent priming study by Jarema et al., (1999), performed in the French language, an interaction between prime and compound type emerged, indicating a larger priming effect with head primes than with modifier primes, but only in head-initial compounds. The authors hypothesized a trade-off between the headedness effect and the first-position effect, which magnifies the latter in head-initial compounds and hides the former in head-final compounds.

Specific compound properties are also reported to modulate the access to constituents. The role of semantic transparency of the compound, which measures to what extent compound semantics is predictable from the constituent meaning (e.g. *carwash vs. fleabag*), was investigated by Sandra (1990), employing a semantic priming paradigm in a lexical decision task with Dutch compounds. The author found that response latencies for target compounds preceded by prime words semantically related to one of the constituents (e.g. *moon* for *Sunday*) were significantly shorter only for transparent targets. These results favor access to both constituents modulated by the semantic traits of the whole compound, but are in contrast with the constituent priming literature (e.g., Zwitserlood, 1994; Jarema et al., 1999; Libben et al., 2003) and with studies on eye-movement in reading (Pollatsek & Hyönä, 2005). The discrepancy between the latter studies and Sandra's study may be imputed to the different methodologies adopted since the two types of priming could affect different levels of processing (Libben et al., 2003). Moreover, a very different classification was adopted in many of these studies: semantic transparency was considered to be a property of the constituents rather than of the compounds (i.e., the authors measured the extent to which the meaning of a constituent was similar to the meaning of the parent compound); this led the authors to introduce semi-transparent compounds (e.g., *strawberry*, in which only one of the constituents is semantically related to the compound). Libben's (1998) model assumes both a lexical and a conceptual level to account for semantic transparency effects, as both these levels would contain a representation of the whole compound as well as independent representations of the individual constituents. However at the lexical level the representation of a compound is always linked to the representation of its constituents, regardless of the underlying conceptual knowledge, explaining the ever-present priming effect in constituent-priming experiments; at conceptual level, on the contrary, the manner in which a compound is represented depends on its semantic transparency: while transparent compounds are linked to their constituent representations (which explains Sandra's (1990) evidence), opaque compounds are not, and therefore are not primed by semantically related words. The importance of semantic transparency in modulating access to constituents at the conceptual level is also partially in line with Juhasz's (2007) results in a sentence-reading experiment, in which the frequency of the first constituent significantly affected go-past duration (an eye movement measure indicating semantic integration), but only for transparent compounds.

Length and frequency of the compound also modulate constituent effects. First, Bertram & Hyönä (2003) manipulated the first-constituent frequency in long and short Finnish compounds. The manipulated variable appeared to modulate the first-fixation duration in long compounds, thus suggesting that compound length facilitates constituent access: the longer compounds are, the more likely they are to be parsed. However, these results were not replicated in English (Juhasz, 2008), and so could be attributed to a language-specific effect. Second, Kuperman, Bertram & Baayen (2008) and Kuperman et al., (2009) found interactions between different frequency measures both in Finnish and Dutch: the more frequent a compound, the smaller the effect of the first-constituent frequency. This interaction emerges as soon as the compound is fixated for the first time, indicating a complex interplay between compound and constituent properties at very early processing stages.

The contribution of neurolinguistics

Neuropsychological studies can be particularly useful in investigating complex word processing for two reasons. First, patients can produce qualitative errors that provide information about the underlying cognitive process, bypassing problems about relying only on quantitative properties of stimuli (e.g., Taft, 2004). Second, the order of magnitude of errors is often considerably greater in neuropsychology than in experimental psychology (Semenza & Mondini, 2006). It is not surprising, then, that some convincing material regarding the unresolved issues about compound processing comes from the neuropsychological field.

In particular, neuropsychological studies on word processing confirmed that, at some level of processing, compounds have to be represented as whole-words. Behrmann, Moscovitch, Black, & Mozer (1990) described an English patient suffering from neglect dyslexia, who read the left-hand side of lexicalized compounds (e.g., *cowboy*) more accurately than that of paired novel compounds (e.g., *suntax*). The effect was consistently present in a series of manipulations of the physical contiguity of the constituents, which were also presented as separated by a single space (*cow boy*) or physically adjacent but separated by a symbol (*cow#boy*); this indicates that the effect does not depend on visual cues, but rather on stored knowledge about compounds: *cow* and *boy* are known to be part of the same compound word, which eases the constituent retrieval. Converging evidence arises from the study of agrammatism: Mondini, Jarema, Luzzatti, Burani, & Semenza (2002) asked two Italian patients to inflect a series of adjectives, which were presented in sentence context. The adjectives could be part of either noun-adjective lexicalized compounds (*croce ross(a)* - red cross), or similar noun phrases (*croce giall(a)* - yellow cross). Patients were able to correctly inflect adjectives in the first, but not in the latter, condition. These results suggest that known, lexicalized, complex words are stored in the lexicon as a whole, and do not simply consist in the juxtaposition of their individual constituents.

However, Semenza et al. (1997) and Mondini et al. (2004) described a phenomenon that strongly contrasts with this conclusion. These authors assessed Broca's and Wernicke's aphasics using a verb-noun compound naming task (verb-noun compounds are grammatically nouns; e.g., portacenere, ashtray, literally "carry-ash"). Broca's aphasic patients are usually impaired in naming verbs: in fact, in these studies, they predominantly omitted the verb constituent (and more often than the Wernicke's patients did). This clearly indicates that constituents must be accessed separately during compound production: if this were not the case, Broca's aphasic patients would not make more errors on the verb constituent, since the compound as a whole is a noun.

The observed results are thus a convincing piece of evidence in favor of mandatory access to constituent representations at the output level, and are in line with the constituent frequency effect described by Rochford & Williams (1965) and Blanken (2000). The frequency of the first component (the modifier) resulted in fact to determine the retrieval performance of patients with aphasia: compounds with high-frequency first constituents were more easily retrieved than compounds with low-frequency first constituents. This result is a further indication of the role played by the constituent morphemes in compound access. Neurophysiological studies on word recognition in normal subjects lead to consistent results: both in visual (e.g., Fiorentino & Poeppel, 2007) and auditory (Koester, Gunter, Wagner & Friederici, 2004; Holle, Gunter & Koester, 2010) presentation, data suggest an early access to constituent representations.

It is less clear whether the constituents are hierarchically organized in the mental lexicon. From a theoretical point of view, it is possible to identify a head- and a modifier-constituent in a compound, the head being the constituent that lends its lexical (grammatical class, gender of nouns) and semantic properties to the compound word (Williams, 1981). There is little evidence whether constituents are actually processed following this hierarchical organization. As in Germanic languages and in Finnish the head is always the rightmost constituent, it is impossible to disentangle the head role from a purely positional effect in these languages but it may be done in Romance languages, in which compounds can be either left- or right-headed. A study on compound naming in bilingual aphasia (Jarema, Perlak & Semenza, 2009) pointed to an interaction between the headedness effect and the effect of the constituent position in the compound. Moreover, an ERP study with a lexical decision task (El Yagoubi, Chiarelli, Mondini, Perrone, Danieli & Semenza, 2008) with Italian speakers showed that right-headed compounds elicit a larger P300 component than left-headed compounds. Since P300 reflects an update of context in working memory, this would suggest that additional processing is requested when the crucial information contained in the head has to be retrieved at the end of the word. These few results suggest that the head-modifier structure is represented at some processing level, but little is yet known about this representation, and more converging evidence is needed.

In conclusion, the neurolinguistic literature is in favor of both whole-word representation and separate retrieval of the morphological constituents, which is at odds with both (de)composition and full-listing models. However, a strictly parallel route model cannot account for the above results either: if the patients' performance were due to an impaired assembling route (as the effect of the constituent grammatical class would suggest), they would still be able to retrieve word representations through the whole-word route; however this prediction was not confirmed by Mondini et al.'s results (2004). The apparently contradictory evidence could be explained in terms of structure representation. Indeed, the knowledge of the compound status of a given word is also represented and stored separately from the phonological word form. The patients' errors tend in fact to reflect the compound status of the target stimulus. In a picture naming task (Semenza et al., 1997), patients produced lexical substitutions that reflected the structure of the target compound noun and, in a similar study conducted by Badecker (2001), were usually aware that their responses were incomplete when a constituent was missing. In a multiple stage model (e.g., Levelt et al. 1999), this structure would be represented at central processing levels, while the constituent forms would be separately accessed at peripheral (i.e., orthographic or phonological lexicon) levels. Since the processing levels can be selectively impaired, this architecture can arguably account for whole-word and compound structure effects (arising because of a central representation) and constituent effects (emerging at peripheral levels).

Overview

This work investigates the processing of Italian compound words in a series of six studies. The main objective of this dissertation is to propose a unified explanation for the whole-word and structure effects observed in compound processing. I will propose that these effects can be accounted for by positing a compound node at the lemma level, i.e., a representational unit binding constituents together into a single lexical unit, along with specifying how these constituents must be combined, and a parallel procedure dedicated to the conceptual combination of constituent meanings. I will also show that much evidence is in line with this theoretical proposal, through a series of experiments in the field of both psycholinguistics and cognitive neuropsychology.

I will start describing an explorative study which investigates whole-word and headedness effects in the context of neglect dyslexia (Chapter 1). Then, I will demonstrate that the headedness effect is consistent across tasks, since the same pattern of results are found in both a constituent-priming experiment on normal participants (Chapter 2) and in the assessment of compound naming errors in patients suffering from aphasia (Chapter 3). These results support an amodal central representation of the compound structure, in line with my proposal in terms of lemma representation. In Chapter 4, I will describe a single case study on deep dyslexia, which strongly suggests that the compound unit is accessed at the lemma level, and that the constituent lemma representations are activated and influence word processing. Finally, I will describe an experiment on constituent frequency effects in lexical decision (Chapter 5), investigating the interplay between semantic and lexical properties which leads to the headedness effect. These results are replicated in an eye-tracking study on compounds read in a sentence frame (Chapter 6), which will shed light on the time-course of the observed effects.

Chapter 1:

The lexical properties of compound nouns influence the reading performance in neglect dyslexia: the effects of morphological structure and headedness.[1]

In this first chapter I will explore how lexical properties of morphologically complex words can influence the reading performance of patients affected by neglect dyslexia (ND). In particular, I will focus on the effects of compound headedness and whole-word representation when reading noun-noun compounds.

Neglect dyslexia is a disorder that mirrors the visuo-spatial difficulties of unilateral neglect in reading tasks (Warrington & Shallice, 1980). In other words, patients affected by ND make errors when reading single words, sentences and texts and these errors concern only one side of the stimuli (usually the leftmost part). ND patients are reported to be sensitive to the lexical properties of the

[1] The final version of this chapter was accepted fro publication in *Neurocase*. The publisher should be contacted for permission to re-use or reprint the material in any form. *Neurocase* is available online at www.tandfonline.com

stimuli. Firstly, a lexicality effect has been reported: although patients may generate neglect errors when reading words as well as non-words (e.g., Ellis, Flude & Young, 1987), a number of studies indicate that the lexical status of the stimuli may modulate the patients' reading performance (see, for example, Behrmann et al., 1990; Caramazza & Hillis 1990a): words are read more easily than non-words, suggesting that the entire stimulus (included the neglected portion) may have been processed at a higher level of processing. Secondly, specific morphological effects were found involving both derived (Arduino et al., 2002) and compound (Behrmann et al., 1990) words. Arduino, Burani & Vallar (2002) showed that ND patients are more accurate in reading derived words with high-frequency roots than with low-frequency roots, and pseudo-affixed non-words formed by real morphemes as opposed to non-existent morphemes, even when these elements are part of the neglected portion of the visual field. Behrmann et al. (1990) described the case of HR, a patient affected by visual neglect whose reading performance was influenced by the lexical and morphemic status of the stimuli rather than their physical parameters. In particular, HR was able to read existing compounds (e.g., *cowboy*) more accurately than juxtapositions of words that do not form an existing compound (e.g., *suntax*).

The present study aims at exploiting the peculiarities of ND to test compound representation in a language (Italian) where the head of compound nouns may be either the first or the second constituent. ND is ideal for testing compound processing; being a spatially-defined disorder in reading, it permits highlighting of the effect of the properties of the leftmost constituent on lexical processing. If the head plays a role during lexical processing, the leftmost constituent will be retrieved more easily when it is head than when it is modifier; this prediction is a direct consequence of previous findings (e.g., Arduino et al., 2002) indicating that salient elements in the neglected field are easier to retrieve. The possibility of whole word access, as well as the mental representation of the compound structure, will also be addressed by comparing the performance of patients when reading existing compounds and word juxtapositions with no lexical status of their own.

Materials and Methods

Participants

Seven right-handed, right-hemisphere brain-damaged patients suffering from left visual neglect participated in the experiment (see Table 1.1). Participants were recruited from the Villa Beretta Rehabilitation Unit (Costa Masnaga, Italy). All patients presented a left visual field deficit assessed by a confrontational visual field testing procedure.

	Gender	Age (yrs)	Education (yrs)	Length of illness (months)	Type of lesion	Lesion site
AC	F	31	11	3	stroke	F, T, P (right)
GB	M	61	5	12	stroke	O, posterior T, BG (right)
EF	F	43	13	5	intracerebral haematoma	deep P (right)
SP	F	53	13	1	stroke	F, T, P, BG (right)
FD	M	61	13	6	stroke	T, P (right)
MR	F	46	11	4	intracerebral haematoma	deep P (right)
MM	F	40	13	8	intracerebral haematoma	missing data (right)

Table 1.1: Demographic and clinical data of the patients participating in the experiment (F= frontal, T= temporal, P= parietal, O= occipital, BG= basal ganglia)

Baseline assessment

Left-visual neglect was assessed by means of a standard battery, comprising two cancellation tasks (*line cancellation test*, Albert, 1973; *bells cancellation test*, Gauthier, Deahut & Joannette, 1989), the *clock drawing test* (Shulman, 2000) and a *copy of geometrical shapes* (Arrigoni & De Renzi, 1964), for which the patients used their unaffected ipsilesional right hand. The results are reported in Table 1.2. Performance on the clock drawing test was coded employing the 6-point scale proposed by Shulman (5: perfect clock; 4: minor visuo-spatial errors; 3 inaccurate representation of clock hands; 2: moderate visuo-spatial disorganization of numbers; 1: severe visuo-spatial disorganization; 0: inability to produce any representation of a clock). Low scores on the clock drawing test were due to errors on the left portion of the stimuli. Copies of geometrical shapes were corrected on the basis of the coding scheme and the norms reported by Spinnler & Tognoni (1987); equivalent scores are employed (4: scores higher than the population median; 3: scores in the 36-50 percentile interval; 2: scores in the 21-35 percentile interval; 1: scores in the 5-20 percentile interval; 0: scores lower than the fifth percentile). Table 1.2 also reports the number of shapes (out of 7) which elicited either left-sided or right-sided errors. Patients were included in this study when they failed at least two out of four tasks.

	Line cancellation		**Bells cancellation**		**Clock drawing**	**Geometrical shapes**		
	Left(10)	**Right(10)**	**Left(17)**	**Right(17)**	**(0-5 scale)**	**E. S. (0-4)**	**Left(7)**	**Right(7)**
AC	3	0	12	4	2	2	2	0
GB	10	3	17	7	2	0	6	0
EF	0	0	17	11	5	1	3	0
SP	5	1	17	11	4	0	4	0
FD	0	0	17	3	3	1	4	0
MR	10	6	17	14	4	0	5	1
MM	5	0	5	2	5	1	3	0

Table 1.2: Baseline assessment of visual neglect. Number of errors in the cancellation tasks (Albert, 1973; Gauthier et al., 1989); performance on the clock drawing test (Shulman, 2002); performance on copying geometrical shapes: equivalent scores (E.S., Spinnler & Tognoni, 1987) and number of shapes eliciting either left-sided or right-sided errors.

The reading performance was subsequently tested in patients who were suffering from visual neglect in this clinical assessment. ND was assessed by means of a reading task composed of words, non-words and a 14-line text. The word list contained 80 stimuli of 2-to-4 syllables (20 high-frequency concrete nouns, 20 low-frequency concrete nouns, 20 high-frequency abstract nouns and 20 function words). The non-word list contained 30 orthographically legal stimuli which were obtained by changing one letter of as many lexical items. Stimuli were presented in the centre of a white PC screen in black lower-case letters (24pt Arial font) for an unlimited period of time. The eye-to-screen distance was 50 cm, and the word and the non-word lists were administered separately. The 14-line text was presented on a white paper sheet, which the participants were free to move as they liked. Errors were registered; these were mostly omissions of words in the left part of the text, but left-lateralized substitutions of parts of words were also observed. Table 1.3 provides a summary of the patients' performance in the reading tasks.

Patients' responses were considered to be neglect errors when the neglect-point condition described by Ellis et al. (1987) was met. i.e., when the target and the response were identical to the right of an identifiable point, and had no letter in common to the left of the same point. It is important to note that all the observed errors affected the left side of the stimuli, even when they did not satisfy the "neglect point" criterion. Patients were included in the study when at least 50% of their (left-lateralized) errors in word or non-word reading could be classified as neglect errors (according to Ellis' criterion) and when they made significantly more errors (omissions and substitutions) in the leftmost, rather than the rightmost, part of the 14-line text. These somewhat loose inclusion criteria were adopted on the basis of Arduino et al.'s (2002) results, indicating that lexical effects are most likely to occur in patients suffering from mild ND only. For this reason, as can be seen in Table 1.3, some of the patients only made a few errors in reading individual stimuli (in particular SP).

	Words (80)		**Non-words (45)**		**Text**			
	Number	**Proportion**	**Number**	**Proportion**	**Left(65)**	**Right(65)**	**χ^2(1)**	
AC	1/2	.50	2/5	.40	50	6	25.6	p<.001
GB	3/6	.50	18/24	.75	65	18	17.1	p<.001
EF	1/1	0	11/13	.85	26	0	22.3	p<.001
SP	1/1	1	0/1	0	28	3	16.7	p<.001
FD	1/1	1	7/11	.64	20	0	17.6	p<.001
MR	4/4	1	6/6	1	65	26	10.1	p<.01
MM	0/1	0	3/4	.75	24	0	20.8	p<.001

Table 1.3: Reading task of individual stimuli (words and non-words): number and proportion of neglect errors (according to the neglect point criterion) out of the total number of leftward errors. None of the observed errors affected the rightmost part of stimulus. Text reading task: number of errors in the left-hand and right-hand section of the text.

Materials

Two sets of stimuli were created. The first contained 48 endocentric compound nouns, i.e., nominal compounds in which one of the two constituents could be unambiguously identified as head. Thirty-five stimuli were noun-noun, six noun-adjective and seven adjective-noun nominal compounds. The latter two classes of stimuli have a very similar head-modifier structure to that of noun-noun compounds, and had to be introduced in order to obtain a sufficient number of stimuli (an analogous procedure was employed in studies on other Romance Languages, e.g., Jarema et al. 1999). Twenty-four stimuli were left-headed (e.g., *pescespada*, “swordfish”, literally fishsword) and twenty-four were right-headed (e.g., *astronave*, “spaceship”, literally starship). Head was identified as the constituent that shares (i) grammatical class, (ii) gender and (iii) semantic category with the compound. Left- and right-headed compounds were matched for length, family size, lemma frequency and surface frequency of both constituents, and lemma frequency, surface frequency, length and age of acquisition of the whole compound. Information about word frequency was obtained from the COLFIS corpus (Laudanna, Thornton, Brown, Burani & Marconi, 1995). Family sizes were computed from the Sabatini & Coletti corpus (2008). Semantic transparency was also controlled, since it has been seen to play an important role in compound processing (Sandra, 1990). A preliminary study had been conducted with 25 students to rate each compound, assessing the extent to which its meaning was predictable from the meaning of its constituents on a four-point rating scale ranging from “very unpredictable” to “very predictable”. The two types of compound resulted to be matched distribution-wise with respect to semantic transparency, i.e., left-headed and right-headed compounds were equally related to the meanings of their constituents. The two compound categories were also matched for imageability of both the compound and its constituents to provide a further control of the semantic properties of the stimuli. Imageability ratings were established by a pre-test on 15 under-graduate or post-graduate students, employing a seven-point Likert scale. Finally, the two groups were matched for the conditional probability of the leftmost constituent given the rightmost one (Kuperman et al., 2008); this was calculated as the ratio between the frequency of the compound and the summed frequencies of all existing compound words ending with the rightmost constituent. This index, which comprises information regarding both frequency and family size measures, is particularly useful for the purpose of the present study, guaranteeing that the leftmost constituent is equally predictable in left-headed and right-headed compounds.

The second set of stimuli consisted of 48 juxtapositions of two existing words that do not form an existing compound. These stimuli were created by substituting the leftmost constituent of the existing compounds described above with an orthographically similar word. These words and the original constituents were matched for lemma frequency, surface frequency, length and orthographical neighborhood size. The rationale behind this matching was to create a list of stimuli very similar to existing compounds, except for their actual lexicality. Thus, for example, the non-word **pestespada*, plaguesword, was created from *pescespada*, swordfish, and the non-word **antronave*, “caveship”, was created from *astronave*, “starship”. Note that in Italian the most productive way of forming new compounds is the concatenation of a verb and a noun (e.g., *asciugacapelli*, *hairdryer*, lit. *dryhair*). Noun-noun (and adjective-noun) compounding is relatively unproductive and this kind of compounds are mostly lexicalised; therefore (and differently from Germanic languages) a novel noun-noun compound (as the stimuli employed in this study) are considered a non-word by native speakers.

Procedures

Stimuli were presented at the centre of a white PC screen in black lower-case letters (24pt-Arial font) so that the left and the right constituents were in the respective hemifields. They were preceded by a central 1500 ms fixation point. In order to increase the error rate and to prevent post-lexical strategies (e.g., go-back fixations after having read the whole compound), the presentation time was limited to 700ms. The eye-to-screen distance was 50 cm. Real and non-existent compounds were listed separately and presented in mixed random order. The patients were asked to read these lists in two separate sessions at an interval of at least two days to prevent priming effects; they were instructed to read the stimuli aloud, regardless of their semantic plausibility.

As GB was unable to fulfill the tachistoscopic task, his performance was tested in an unlimited time condition.

Data Analysis

As the aim of the study was to investigate access to constituent representation and the application of the neglect point procedure developed by Ellis et al. (1987) might have excluded some informative phenomena (e.g., the substitution of the leftmost constituent with an orthographically similar word), I simply distinguished between “leftward” (regarding the leftmost element) or “rightward” (regarding the rightmost element) errors. Perseveration and no-responses were classified as “other errors” and excluded from the subsequent analyses. Leftward errors were further classified as “substitutions”, “omissions” and “mixed errors” (i.e., omissions+substitutions and/or additions). The objective of this qualitative analysis was to investigate the different reading strategies adopted by the participants.

Both group and single-case analyses were run, aimed at assessing a headedness effect (comparing left-headed vs. right-headed compounds) and a lexicality effect (comparing existing compounds vs. non-existent compounds).

Paired-sample t-tests were employed in the group analysis, with a “neglect-error index” as dependent measure. This index was calculated as the number of leftward errors minus the number of rightward errors, divided by the number of stimuli. Therefore the index ranged from -1 (errors in the rightmost element for all stimuli) to +1 (errors in the leftmost element for all stimuli). Rightward errors were introduced as a negative component because they play directly against the premise of this study, i.e., to study compound representation by means of left ND. This correction ensures that the analyses are more conservative without losing potentially informative data.

Two-by-two chi-square tests were employed in the single-case analyses, comparing the number of correct readings to the number of leftward errors in left-headed vs. right-headed compounds, and the number of correct readings to the number of leftward errors in compounds vs. non-existent compounds. When required by the data, Fisher’s exact test was substituted for the chi-square test.

Regression analyses were also run to evaluate the effect of the relevant psycholinguistic variables on the patients’ performance. These analyses had a two-fold objective: to confirm the results of the group analysis, and to ensure that the results would in no case depend on manipulation related to the “neglect error index”. In fact, logit mixed effects models (Jaeger, 2008) were applied to raw data in order to evaluate which variables influence the likelihood of committing the different types of error. Three separate models were run, taking into consideration (i) the likelihood of errors affecting the left-hand constituent, (ii) the likelihood of errors affecting the right-hand constituent, and (iii) the likelihood of committing other kinds of errors. The dependent dichotomic variable in each model was coded as follows: 1 for the occurrence of the specific error, 0 for other types of outcome (different error types or unimpaired reading). Non-independency of observations was handled by introducing random effects, i.e.; inter-subject and inter-item variance were accounted for by the corresponding random intercepts (Baayen, Davidson & Bates, 2008; Jaeger, 2008). Surface frequency and orthographic neighborhood size of the leftmost and of the rightmost element were introduced as independent variables, as were semantic transparency, surface frequency, and headedness of the whole compound. Moreover, the interaction between headedness and semantic transparency was introduced to assess whether the headedness effect might be associated with the semantic relationship between a compound and its constituents. The condition number κ was computed in order to check for possible collinearity-related concerns, and in accordance with Belsley, Kuh & Welsch (1980), the intercept was also taken into account when calculating κ. In order to reduce collinearity, highly correlated variables were orthogonalized, as in the method described by Kuperman et al. (2008). A full-factorial model was taken as the starting point; during the phase of model criticism, a reduced set of regressors was chosen employing a stepwise method: predictors were removed only if their absence did not significantly affect the goodness of fit of the model (i.e., the result of the likelihood ratio test comparing the goodness-of-fit of the model before and after removing the effect of each parameter was not significant; see Baayen, 2008). Once the models were fitted, atypical outlier responses were identified and removed (employing 2.5 SD of the residual errors as criterion). The models were then refitted to ensure that the results were not driven by a few excessively influential outliers. Separate analyses were run for real and non-existent compounds.

Results

Headedness effect

In the group analysis the headedness effect emerged as significant ($t(6) = 2.52$; $p < .05$): patients were able to read left-headed better than right-headed compounds, e.g., they made more errors when reading *astronave* than when reading *pesc<u>e</u>spada*. Table 1.4 summarizes the raw number of errors and the neglect-error index for each patient, as well as the results of the single-case analyses (chi-square and Fisher’s tests).

	Stimuli	R+	Errors			$\chi^2(1)$	Neglect error index
			Leftward	Rightward	Other		
AC	Left-headed comp. (24)	22	0	0	2	p<.05*	0
	Right-headed comp. (24)	14	4	2	4		.10
GB	Left-headed comp. (24)	18	5	0	1	.34 n.s.	.22
	Right-headed comp. (24)	17	7	0	0		.29
EF	Left-headed comp, (24)	21	3	0	0	n.s.*	.13
	Right-headed comp. (24)	17	5	1	1		.17
SP	Left-headed comp, (24)	16	4	0	4	1.16 n.s.	.20
	Right-headed comp. (24)	15	8	0	1		.35
FD	Left-headed comp, (24)	18	3	2	1	n.s.*	.04
	Right-headed comp. (24)	16	7	0	1		.30
MR	Left-headed comp, (24)	10	11	1	2	.67 n.s.	.45
	Right-headed comp. (24)	7	13	0	4		.65
MM	Left-headed comp, (24)	19	3	0	2	n.s.*	.14
	Right-headed comp. (24)	20	3	1	0		.08

Table 1.4: Patients' errors, classified by type of compound, and single case analyses of headedness effect; *= Fisher's exact test.

The group analysis results are not completely replicated in the single-case analyses, since a significant headedness effect emerged in only one patient (AC). However, both raw data and neglect errors index indicate that almost all patients (except MM) tended to make fewer neglect errors in left-headed compounds, thus suggesting an effect, albeit small. The apparent inconsistency between the two analyses could then be explained by the low statistical power of the non-parametric tests employed in the single-case analyses. Errors were also classified as omissions (e.g., *astronave, starship* → "nave", ship), substitutions (*<u>giro</u>vita,* waist measure, lit. waistcircle → "*<u>caro</u>vita*", (high) life cost, lit. <u>dear</u>life) and mixed errors. This latter category comprises two types of errors that are rarely observed, i.e., the addition of letters in the leftmost part of the stimuli and a combination of substitutions and omissions. No clear and steady error pattern emerged, with the noteworthy exception of MR who constantly omitted the leftmost constituent.

Lexicality effect

In the group analysis the whole-word effect is significant (t(6) = 5.16; p < .001): non-existent compounds (e.g., **pestespada*) elicited more leftward errors than the paired real compounds (e.g., *pescespada*). As summarized in Table 1.5, the single-case analyses confirmed the significant lexicality effect in all patients.

	Stimuli	R+	Errors			$\chi^2(1)$		Neglect error index
			Leftward	Rightward	Other			
AC	Compounds (48)	36	4	2	6	7.1	p<.01	.05
	Non-existent comp. (48)	24	13	4	7			.22
GB	Compounds (48)	35	12	0	1	20.6	p<.001	.30
	Non-existent comp. (48)	13	34	0	1			.72
EF	Compounds (48)	38	8	1	1	64.8	p<.001	.15
	Non-existent comp. (48)	0	46	1	1			.96
SP	Compounds (48)	31	12	0	5	8.1	p<.01	.28
	Non-existent comp. (48)	17	24	0	7			.59
FD	Compounds (48)	34	10	2	2	29.2	p<.001	.17
	Non-existent comp. (48)	9	36	0	3			.80
MR	Compounds (48)	17	24	1	6	13.8	p<.001	.55
	Non-existent comp. (48)	3	40	0	5			.93
MM	Compounds (48)	39	6	1	2	28.7	p<.001	.11
	Non-existent comp. (48)	14	31	0	3			.69

Table 1.5: Patients' errors, classified by type of stimulus (compounds vs. non-existent compounds), and single case analyses of the lexicality effect.

However, from a qualitative point of view, performance differs across the individual patients (see Table 1.6). When reading non-existent compounds, two out of seven patients (EF and MR) tended to omit the leftmost element, reporting only the rightmost portion of the stimuli (*pestespada, plaguesword* → "spada", sword); four patients (AC, SP, FD and MM) tended to substitute the leftmost element, typically producing the corresponding real compound (*pestespada, plaguesword* → "pescespada", *swordfish, lit. fishsword*)]; in one patient (GB) most of the errors were on the left constituent, but with no clear difference between the two types of errors. Headedness of the original compounds did not affect the patients' performance on the paired non-existent compounds.

	Stimuli	Leftward errors	Omissions	Substitutions	Mixed errors
AC	Compounds (48)	4	1	2	1
	Non-existent comp. (48)	13	3	8	1
GB	Compounds (48)	12	5	7	0
	Non-existent comp. (48)	34	18	16	0
EF	Compounds (48)	8	5	2	1
	Non-existent comp. (48)	46	30	15	1
SP	Compounds (48)	12	5	7	0
	Non-existent comp. (48)	24	4	19	1
FD	Compounds (48)	10	7	3	0
	Non-existent comp. (48)	36	8	28	0
MR	Compounds (48)	24	23	1	0
	Non-existent comp. (48)	40	36	4	0
MM	Compounds (48)	6	1	5	0
	Non-existent comp. (48)	31	3	27	1

Table 1.6: Qualitative analysis of leftward errors, classified by type of stimulus (compounds vs. non-existent compounds).

Modulation of psycholinguistic variables

First of all, a series of logistic mixed analyses were performed on the compound stimuli. The surface frequency variables were partialled out from the semantic transparency predictor (see Kuperman et al., 2008) as they were significantly correlated with semantic transparency. The resulting set of predictors was associated to a low κ (6.5). The effects of headedness and of the first-constituent frequency significantly influenced the likelihood of leftward errors. Left-headed compounds elicit significantly fewer leftward errors than right-headed compounds ($B=-.75$, $z=2.02$, $p<.05$). The effect of the first constituent frequency indicates that the higher the frequency of a left constituent is, the less often it is affected by errors ($B=-.002$, $z=2.69$, $p<.01$). On the contrary, none of the variables emerged as a significant predictor in the models describing rightward and other errors. In other words, the occurrence of these types of error is mainly associated with inter-subject and inter-item random variance, and thus is not influenced by the lexical properties of the stimuli.

No effect emerged in the models run for non-existent compounds (κ= 6.1): none of the variables had a significant effect on any of the error types for this kind of stimuli.

Discussion

The present study used ND as an experimental model condition to investigate the mental processing of compound nouns. Two main issues were addressed: the representation of headedness and the possibility of a whole word access to compounds. Seven neglect dyslexic patients were assessed in a reading task of compounds and paired non-existent compounds. The patients' performance on both left-headed and right-headed compounds and on real and non-existent compounds was compared.

A headedness effect emerged in the group analysis: the left constituents (i.e. the head) of left-headed compounds were read more accurately than the left constituent (i.e. the modifier) of right-headed compounds. Since the two types of compound stimuli were matched for the relevant psycholinguistic variables, this effect can be explained by the assumptions that (i) lexical information in the neglected hemifield is processed (at least implicitly; see Marshall & Halligan, 1988), and (ii) the head and the modifier constituents are represented differently in the mental lexicon. This result is highly consistent with the data recently obtained by Semenza, Arcara, Facchini, Meneghello, Ferraro et al. (2011) in a different experimental paradigm.

Previous studies on neglect dyslexia (e.g., Arduino et al., 2002) have shown that the lexical properties of the stimuli affect the patients' reading performance. The present results are in line with these conclusions: head constituents are particularly salient because of the underlying lexical characteristics (their grammatical properties are extended to the whole compound) and are in fact easier to retrieve than modifiers. Alternatively, the headedness effect could be explained on the basis of the semantic rather than the lexical properties of the head of the compound: in fact semantic properties of the stimuli have also been shown to affect the patients' performance in ND (Vallar, Guariglia, Nico & Tabossi, 1996). In other words, assuming that the head constituent carries most of the compound's semantic information, patients would make fewer errors on left-headed than right-headed compounds because the left side of a left-headed compound is more semantically salient than the left side of a right-headed compound. However, there is a widespread misconception that the head of a compound is always the most semantically relevant constituent; Libben et al. (2003) and Inhoff et al. (2008) demonstrated that in English the meaning of the modifier is frequently more strongly related to the sense of the entire compound than the meaning of the head (e.g., *staircase*) and the dissociation between headedness and semantic saliency has also been shown in French (Jarema et al., 1999). In fact neither the interaction between semantic-transparency and headedness nor the main effect of semantic transparency emerged as significant from the regression analyses in the present study. If it were true that semantic properties are important in modulating these patients' errors, performance on constituents with a stronger semantic relationship to the meaning of the whole compound should have been better, at least in left-headed compounds, but actually this was not the case. Therefore, while semantic properties could also partially account for a headedness effect, an explanation relying on semantic aspects only is far from satisfactory, both in theoretical and empirical terms.

The comparison between existing and non-existent compounds indicates that real compounds are read better than non-existent compounds: the leftmost element is easier to access when part of a real compound. This lexicality effect is in line with the results obtained by Behrmann et al. (1990), but in that experiment the non-lexicalized compounds were built as juxtaposition of two unrelated words (e.g., *suntax*). Therefore compound stimuli (e.g., *cowboy*) had an intrinsic facilitation compared to non-lexicalized compounds, i.e., their rightmost, non-neglected element (e.g., *boy* vs. *tax*) was known to be potentially part of a compound and could thus have elicited a search for another element in the neglected side of the stimuli. In the present study, the right constituents of non-existent compounds were taken from real compounds, unlike those in Behrmann et al.'s non-existent compounds. In addition, the two types of stimuli were orthographically very similar, since only one/two letters differed in the leftmost part of the stimulus (**pestespada* vs. *pescespada*). Moreover, non-existent compounds and their real counterparts were matched for the relevant psycholinguistic variables, ensuring that the only differences between the two types of stimuli were lexicality and the underlying hierarchy: compound stimuli were juxtapositions of real words forming a real (complex) lexical entry; non-existent compound stimuli were juxtapositions of real words not forming an existing lexical entry. Therefore, the lexicality effect cannot be explained either as a facilitation of the non-neglected element (since it was the same in compounds and non-existent compounds alike), nor as the effect of different properties of the leftmost element (due to the accurate matching).

It could still be argued that this effect is due to methodological manipulation: since non-existent compounds are very similar to known compounds and patients are aware of the defective representation in their left hemispace, participants might employ a guessing strategy to compensate their impairment. Indeed, the qualitative analysis of errors indicates that patients tended to lexicalize non-existent compounds (*pescespada* for **pestespada*), leading to a majority of substitutions of the leftmost constituent of the compound. However, if the lexicality effect is explained in terms of a guessing-strategy, it follows that when this strategy is not applied, the effect will disappear. However this was not the case: two patients (EF and MR) frequently omitted the leftmost element of non-existent compounds rather than substituting them, thus refuting the possibility that they were using a guessing strategy. Nevertheless, their performance was characterized by significant lexicality effect, as was that of the other five patients. Therefore, the hypothesis of a guessing strategy cannot account for the observed effect, which also emerges when the strategy is clearly not adopted. Moreover, if the patients had had recourse to a guessing strategy, they should also have produced verb-noun nominal compounds (e.g. *capolinea* → $[\text{guarda}_V \text{linea}_N]_N$, *linesman*, lit. “lookline”), since this type of nominal compounds is the most productive in Italian. This however was not the case.

Alternatively, substitution (or omission) errors may reflect implicit response styles (e.g., Arduino et al., 2002), rather than an explicit strategy to compensate for the degraded processing of the left-hand information. This is supported by the observation that EF and MR also made a substantial number of omissions when reading existing compounds, while the other patients (with the exception of FD) made a substantial number of substitutions. It would therefore appear that each patient showed a specific response style (omission vs. substitution).

This alternative hypothesis would also dismiss the explanation of the lexicality effect in terms of an epiphenomenon of the guessing strategy.

However, for the purposes of the present study, it is not crucial to establish which of the above interpretations is correct. Indeed, both alternatives indicate that a guessing strategy cannot fully account for the present results, and that the lexicality effect does indeed depend on the properties of the stimuli (existing vs. non-existent compounds).

This lexicality effect indicates that compounds and non-existent compounds undergo different mental operations and presumably is based on the lexicality of real compounds. Reading non-existent compounds requires access to two separate lexical representations; as the first element appears in the left side of the screen, ND patients will probably not perceive it. However, when patients read real compounds, the fact that the two constituents are represented in the mental lexicon as a unique lexical entry facilitates the retrieval of the leftmost element.

The parsing hypothesis is supported by the regression analysis dedicated to compound stimuli, in which a left-constituent frequency effect was found as well as a consistent headedness effect: the more frequent the constituent, the more easily it is retrieved. Indeed, this effect suggests that the individual constituents have a role in the lexical access even when they appear in the neglected side of the screen, and confirms the results of other studies that indicate lexical effects in ND (e.g., Arduino et al., 2002). Noteworthy, no effect emerged in the regression analysis dedicated to non-existent compounds, not even the constituent frequency effect. This means that the left-constituent frequency effect emerging in the real-compound analysis does not simply depend on the role of the left-constituent representation; if this had been the case, a similar result should have emerged for non-existent compounds as well, which are necessarily constituted of two separate lexical entries. Therefore, left-constituent representation does play a role in the processing but only when it is part of a compound, suggesting a complex interplay between compound and constituent representation during mental processing.

The headedness effect, the left-costituent frequency effect (suggesting a parsing procedure), and the lexicality effect (suggesting whole-word access) are only apparently in conflict: as described above, they are in line with a dual-route approach (Schreuder & Baayen, 1995).

But how can lexical representations influence the reading performance of ND patients? Arguably, processing of the left-hand portion of the stimuli does occur, albeit somewhat degraded. As the occurrence of substitution errors suggests (Table 6), there could be sufficient perceptual processing to obtain at least partial information regarding letter identity and/or position (information which occurs at a very early phase: Popple & Levi, 2005; Strasburger, 2005). This procedure would be further hindered by the brevity of the presentation time adopted in the present study (700 ms): in fact, patients who performed well on the unlimited baseline assessment (especially SP) made more neglect errors during the experimental tasks. The amount of information that can be acquired in 700 ms is limited by the visual span (Chung, Mansfield & Legge, 1998; Legge, Mansfield & Chung, 2001); since it is possible to process only 5 to 10 letters around a fixation position (Legge et al., 2001), and some of the compounds employed in the reading task were longer than 10 letters, saccades may be needed to process the whole letter string. Only one or two glimpses would be possible in 700 ms, and the first saccade would usually be centered on the right side of the word (Di Pellegrino, Làdavas & Galletti 2002). Under these conditions ND patients would be able to perceive only a few letters, especially on the left-hand side. This degraded visual processing could account for some of the results (e.g., the lexicality effect observed when reading simple words, as stated in the Introduction). However, a purely peripheral account would not explain why fewer letters are needed to identify the target stimuli in left-headed compounds compared to those needed for right-headed compounds. The same reasoning could be applied to the compound lexicality effects (see also Behrmann et al., 1990). No elements in the visual-orthographic properties of the stimuli typify the mentioned variables (headedness and compound structure); the difference between left- and right-headed compounds, and between real and non-existent compounds, has to be represented as stored lexical knowledge. Given that the adopted conditions considerably limit the potential visual processing (as described above), the partial orthographic information could not be sufficient to allow ND patients to access the required high-level representations. In fact, the results obtained in this study on compound reading would appear to require an explanation in some form of implicit processing. The access to high level lexical information is in line with several results indicating that ND patients are aware of lexical and semantic properties of stimuli that they cannot read aloud (Làdavas, Paladini & Cubelli, 1993; Làdavas, Umiltà & Mapelli, 1997); this spared lexical awareness could lead to the facilitation observed for more salient lexical items (i.e., head constituents and existing compounds). This interpretation would fit the hypothesis of a representational disorder underlying the neglect impairments (Bisiach & Luzzatti, 1978; Caramazza & Hillis, 1990b).

What type of lexical architecture would best fit the patients' performance? As a first hypothesis, the present results could be interpreted by adopting a theoretical frame of the lexicon that conceives separate lemma and lexeme representations (Levelt et al.,1999; Crepaldi, Rastle, Coltheart & Nickels, 2010). Word forms are stored independently at the lexeme level, each with its own activation threshold depending on its frequency. Only superficial representations of words are accessed at this level, i.e., neither grammatical nor semantic effects can emerge. Arguably, input orthographic representations and output phonological representations are organized in separate stores. On the contrary, abstract representations of words are stored at the (modality-independent) lemma level, which contains syntactic and partially semantic information. In other words, the lemma level stores grammatical properties of words, which are necessary for integration in higher-order structures (i.e., sentences). Compound word representations in this kind of model are not straightforward. Each compound probably has its own lemma node representing its structure, since the lexical and semantic properties of a compound are not directly deductible from its constituents (Badecker, 2001). How a compound is represented at lexeme levels is still unclear; in particular it is not clear whether it has its own representation or depends on separately stored constituent representations. the present results are more coherent with the second hypothesis. The following paragraphs provide a description of how the interplay of lemma and lexeme representations could give rise to the observed effects.

Lexical effects in ND seem to arise from an influence of the lexical system on visual encoding (Arduino et al., 2002; Vallar, Burani & Arduino, 2010): orthographic information is easier to process when related to salient lexical items. For this reason, when reading noun-noun nominal compounds, the more frequent the left constituent is, the easier it is for ND patients to retrieve it. However, this effect was found only for existing (lexicalised) compounds: a clarification of the lexicality effect is therefore crucial in order to model the constituent-frequency effect. Arguably, the lexicality effect found in this study emerged at lemma level: indeed, existing compounds and non-existent compounds differ in their lemma representation (see Figure 1.1). The structure of the compounds can be accessed, since a unique lemma node receives converging activation from both the right constituent representation and the – degraded – left constituent representation. This would result in the correct naming of the whole compound (a single compound lemma node activating the two output lexemes), which explains the better performance on real compounds as opposed to non-existent compounds. The latter stimuli, by definition, do not have a whole representation at lemma level and two separate lemma representations have to be accessed. Thus the left lexeme at the output level remains unreported (see Figure 1.1).

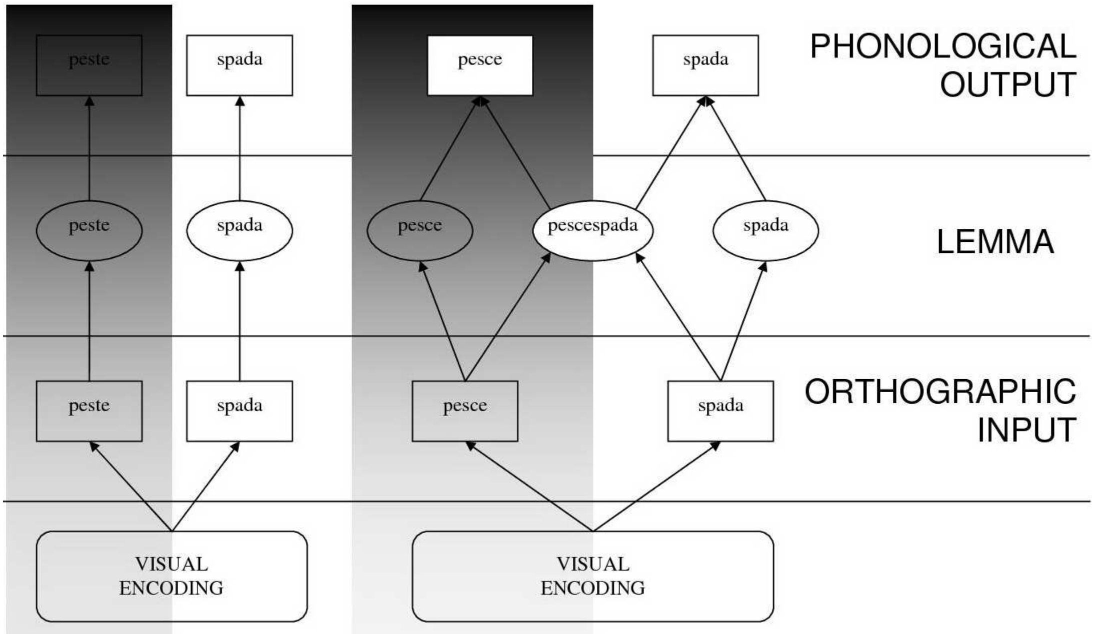

Figure 1.1: Example of the processing of non-existent compounds and real compounds by neglect dyslexic patients.

Separate constituent representations at the orthographic input level are in line with the psycholinguistic literature reviewed in the introduction, and are confirmed by the results of the regression analysis conducted in the present study. Indeed, both the left-constituent frequency effect and the headedness effect arguably arise at the interplay with the lemma level. In other words, the amount of activation spreading from the left-constituent representation to the lemma node depends on the lexical saliency of the peripheral element (i.e., highly frequent constituents facilitate access to the lemma node to a higher degree). The headedness effect may emerge for a similar mechanism: assuming that compounds have a stronger lexical relationship with their heads than their modifiers, a higher degree of activation would spread from the head constituent, resulting in a better reading performance on left-headed compounds.

It is interesting to note that input representations also activate semantic properties, which could directly mediate an access to the phonological output level (as described in the model proposed by Caramazza, 1997). However, for the reasons already discussed above with reference to the headedness effect, I believe that focusing on the grammatical properties of the stimuli provides a more economical explanation of the present results.

The data resulting from the present study are obtained from the analysis of the reading performance of ND patients, and therefore mainly provide information regarding the input processing stages. It follows that the structure of the output level I have proposed is mainly speculative. The results of previous studies on compound picture naming indicate either a whole-word output representation (e.g., Janssen et al., 2008) or a separate access to the single constituents (e.g., Mondini et al., 2002). In the model proposed here, the latter representation was implemented, as it appears to be more suitable for the Italian language (Semenza et al., 1997; Mondini et al., 2002).

Converging evidence in favor of the proposed model will be provided in the next chapters. First, I will address the issues related to compound headedness and compound structure, and in particular I will seek results indicating that these properties are represented at the lemma level.

Chapter 2:

Head-initial and head-final compounds are differently processed in the mental lexicon: a constituent priming study.[2]

The results of the previous study clearly indicate that the role played by either constituents of a compound (head vs. modifier) is represented in the mental lexicon. The head-modifier structure is a property of compound nouns, which is retrieved during lexical processing. However, even if both head-initial and head-final compounds were used, the study could not clearly disentangle the effect of headedness from an effect of constituent position: being ND a spatial disorder that almost always involves the left spatial representation, only the processing of left-constituents could be examined and, eventually, results relied on a comparison between head-initial and head-final compounds, rather than on the different processing between the head and the modifier of the same compound.

[2] The final version of this chapter was published as Marelli, M., Crepaldi, D., & Luzzatti, C. (2009). Head position and the mental representation of. Italian nominal compounds. *The Mental Lexicon*, 4, 430-455.
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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

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 (*foto/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 et al., 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).

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 2.1: variables considered in Experiment 1 and their levels

Three factors were considered (see Table 2.1). Participant and item were introduced as crossed random effects.

Results

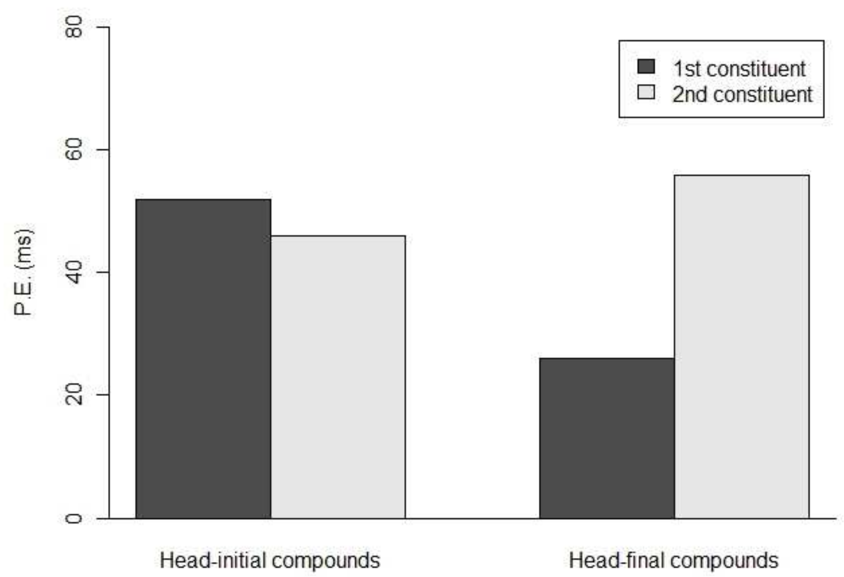

Figure 2.1: Priming Effect (P.E.) on response times for the first and second constituents in head-initial and head-final compounds

Figure 2.1 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. 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. 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.

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 2.2: 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.

The estimated parameters of the final model are reported in Table 2.2 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 2.2, 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).

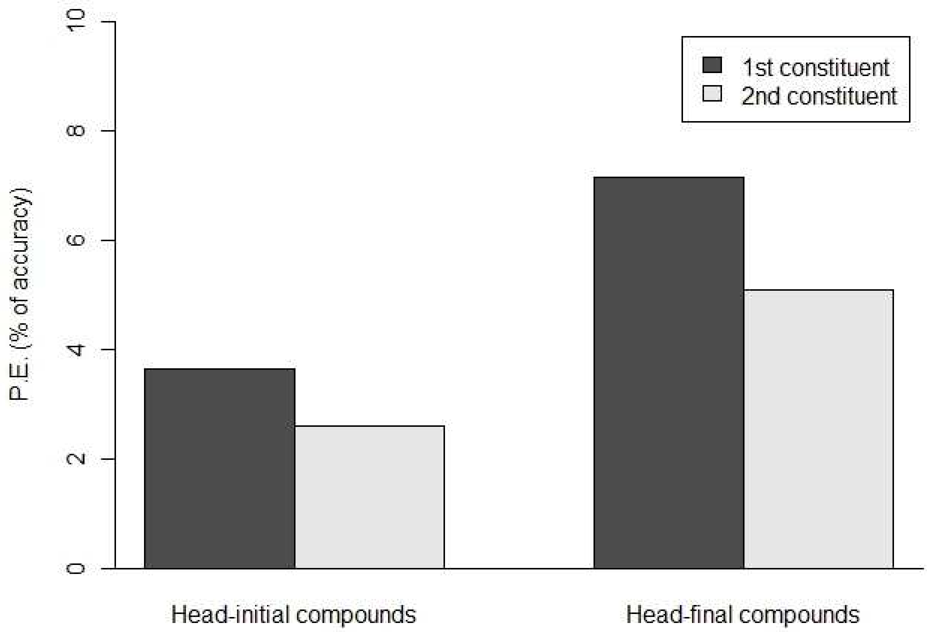

Figure 2.2: Priming Effect (P.E.) on accuracy for the first and second constituents in head-initial and head-final compounds

Figure 2.2 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 facilitation 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

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, *lavastoviglie* (‘dishwasher’, lit. ‘washes’-‘dishes’) is not a kind of dish. The head is therefore an implied element, external to the compound itself.

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

A facilitation was found both when the first constituent was used as prime (51 ms) and when the second constituent was used as prime (63 ms). 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. 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.

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

Table 2.3: 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.

The estimated parameters of the final model are summarized in Table 2.3. The effect of PT was found to be significant. The model indicates an overall priming effect of about 60 ms, and no significant interactions.

Priming effects were observed also on accuracy (first constituent: 3.65 %; second constituent: 2.6 %). 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, 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.

The assumption of right-headedness in a Romance language such as Italian may thus seem counterintuitive. In fact, both head-initial and head-final compounds are equally acceptable to native Italian speakers; neither of these constructs is explicitly considered irregular or exceptional. However, the two compound types seem to differ for several properties. In the first place, it appears that the word formation processes that subtend them are very different (Fu, 2000): while head-final compounds would have a genuinely morphological origin (in analogy with derived words), head-initial compounds would be the lexicalization of a syntactic structure. In the second place, the origins of head-initial compounds are mainly medieval, while head-final compounds originate from Latin and ancient Greek compounds or are generated on a calque of Latin/Greek compounds (Dardano, 1978). These considerations have indeed led Scalise (1984) to claim the superiority of left-headedness in Italian compounding. However, this traditional view was challenged by Schwarze (2005), and is not completely corroborated from a quantitative point of view. A cross-linguistic analysis has shown that head-final compounds are dominant in all the linguistic families under scrutiny (Guevara & Scalise, 2008), including Romance languages, where they represent 38% of the compounds (in comparison to the head-initial compounds which represent only 18%). To further support this data, I examined the compounds listed in the Sabatini &

Coletti corpus (2008, 154,000 lemma entries). My first analysis, which included all compound nouns containing either two nouns or a noun and an adjective, revealed a total of 885 left-headed and 927 right-headed nominal compounds. However, neoclassical compounds (i.e., compounds whose constituents are not free morphemes in Italian, but content bound morphemes of Latin or Greek origin, as *biologia*, biology) were extensively represented in the corpus (more than 10,000 entries). These constructs are always head-final, thus confirming the analysis of Guevara & Scalise (2008), and indicating the significant presence of head-final compounds in Italian. Taking these data into consideration, it can be hypothesized that the effect observed may not be the result of the application of an abstract top-down rule, but rather the appreciation of the distributional properties of the Italian lexicon: the head-initial structure represents only a minority of Italian complex words, and the head could be searched in the final position simply because it is most likely to be found there.

The hypothesis of an internal hierarchy for head-final compounds only 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.

Chapter 3:

The representation of compound headedness in the mental lexicon: a naming study on aphasic patients.

The study reported in the previous chapter has shown that head-initial and head-final compounds undergo different cognitive processes. Results suggest that head-final compounds are hierarchically represented (Williams, 1981), that is, their heads play a more prominent role in word processing, in comparison to their modifiers. In accessing head-initial compounds, on the contrary, head and modifier constituents are equally important. Those results may be due to the task employed in the previous experiment: when asked to recognize compounds as fast as possible, subjects may adopt different strategies for different compound structures.

However, following the interpretation proposed in Chapter 1, the effect should depend on the representation of the compound structure, which differs between head-initial and head-final compounds. If the compound structure is represented at central level, a direct prediction is that a similar effect should be observed in tasks other than lexical decision, especially those tapping into output processing levels. In the present study I will test this prediction by analyzing the performance of neuropsychological patients in a picture naming task. If the effect elicited by the priming paradigm is due to the representation of the compound structure, a similar pattern should be observed in the errors made by patients when naming compound words. The study was structured in two main phases. The first (preliminary) phase was meant to select the patients that would be included in the subsequent experimental phase. A disproportionate impairment in naming complex words, in comparison to simple words, was adopted as inclusion criterion. In the experimental phase, I zoomed in on compound naming, performing a qualitative analysis of the patients' errors.

PRELIMINARY PHASE

Materials and methods

Participants

A total of 142 patients with focal LH brain lesions were examined. All participants were suffering from mild-to-moderate aphasic impairments, as evaluated by the Italian version of the Aachener Aphasie Test (Luzzatti, Willmes & De Bleser, 1996). Patients were recruited at the "Fondazione Salvatore Maugeri" Rehabilitation Centre, Montescano (Pavia).

Materials

A confrontation naming battery was employed, which consisted of 145 stimuli that could be either pictures or definitions of Italian entities. 57 stimuli represented objects with a simple noun, while 88 stimuli represented objects with a complex noun. Complex target words were either derived nouns (36 stimuli; e.g., *campanile*, bell tower, derived from *campana*, bell) or compound nouns (52 stimuli; e.g., *pescespada*, swordfish, literally fishsword). One-hundred and ten items were presented as pictures, while 35 (low-imageability) items were presented as definitions: in a preliminary naming study, each stimulus had elicited the expected target word in at least 80% of the control participants.

Procedure

Stimuli were presented in a unique list, comprising both simple and complex words, in a randomized order. Patients were asked to produce the noun corresponding to each definition/picture. Responses were considered correct only within a 3-second interval from stimulus presentation. Minor phonological alterations and articulatory distortions were ignored.

Data analysis

Patients' performances were individually assessed in order to uncover dissociations between complex and simple word naming. For each patient, a logistic regression analysis was employed to predict the likelihood of a correct response on the basis of the stimulus category (complex vs. simple noun). Stimulus length was introduced as a covariate, to rule out its influence on the patient's performance.

Results

91 patients, out of the 142 assessed, suffered from disproportionate impairment in producing morphologically complex words in comparison to simple words. The effect cannot be explained in terms of stimulus length, which has an independent (additive) effect on the patients' performance. The included patients had been previously classified as suffering from Broca's aphasia (7), anomic aphasia (15), conduction aphasia (5), Wernicke's aphasia (4), residual aphasia (52), and other aphasic forms (8).

EXERIMENTAL PHASE

Materials and methods

Participants

In this phase I reanalyzed the performance of the 91 patients who showed a disproportionate impairment of morphologically complex words.

Materials

Two sets of compound nouns were extracted from the naming task analysed in the previous phase. The first set comprised 16 compounds in which the first constituent was the morphological head of the compound noun (head-initial compounds; e.g., *pescespada*, swordfish, literally fishsword); the second set included 14 compounds in which the second constituent was the morphological head of the compound (head-final compounds; e.g., *autostrada*, highway, literally carway). The sets were matched for a series of psycholinguistic variables (word frequency and length of both the compound and its constituents, semantic transparency, age of acquisition, imageability) and for the proportion of stimulus types (pictures vs. definitions).

Procedure

The performance with the compound stimuli was reanalyzed qualitatively. The focus of this new analysis was the accuracy in retrieving the individual constituents, that is, for each stimulus, I considered whether either constituents were correctly reported, irrespective of the accuracy in retrieving the whole compound. As a consequence, two distinct dependent measures were associated to each stimulus: the accuracy in reporting the first constituent, and the accuracy in reporting the second constituent.

Data analysis

The accuracy in retrieving either constituents was analysed employing a logistic regression. The peculiar properties of the dependent variable (being measured twice for each stimulus) and the intent of running a group study would necessary lead to issues related to the non-independency of observations, in a traditional Generalized-Linear-Model framework. For this reason, a mixed-effects analysis (Jaeger, 2008) was employed: specifying a nested structure including the random effects of participants, compounds and constituents, it is possible to prevent potential problems in parameter estimation related to the fact that observations are not independent. Stimulus type (definition vs. figure) was also included as an additional random effect.

The main effect of interest was the interaction between the position of the constituent considered (first vs. second position) and compound headedness (head-initial vs. head-final compounds). The psycholinguistic variables described above were also introduced as covariates. All predictors were mean-centred, in order to ensure a better estimation of the parameters in the subsequent analyses (Kraemer & Blasey, 2004). A backward procedure was followed in order to simplify the statistical model: starting from a full-factorial model, predictors were removed one by one when their absence did not worsen significantly the overall goodness of fit. Once the model was fitted, atypical outliers were identified and removed (employing 2 SD of the residual errors as criterion). The model was then refitted to ensure that the results were not driven by these overly influential outliers (Baayen, 2008).

Results

FIXED EFFECTS	Parameter	z-value	p
Intercept	-.19	.74	.462
Headedness	-.26	1.29	.198
Constituent Position	.08	2.32	.021
Costituent Pos. x Headedness	.22	5.94	<.001
Age of Acquisition	-1.28	5.84	<.001

RANDOM EFFECTS	Variance
Participants	2.66
Constituent	.27
Compound	.95

Table 3.1: fixed and random effects introduced in the final model describing the aphasic patients' performance on a picture naming of compound nouns

The final model included the interaction between headedness and constituent position, and age of acquisition as significant predictors. The parameters of the model are reported in Table 3.1. The random effect associated to stimulus type (definition vs. picture) did not improve significantly the goodness-of-fit of the model, and was thus removed from the analysis.

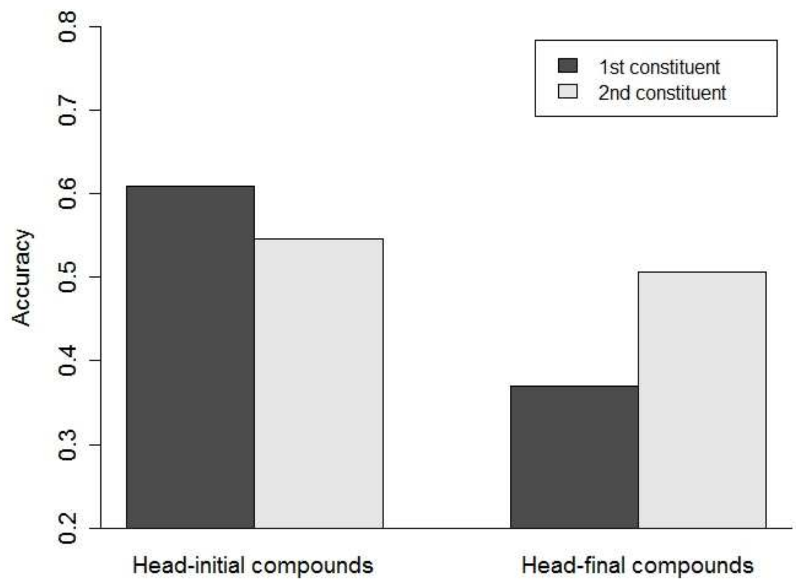

Figure 3.1: accuracy in retrieving either constituents in head-initial and head-final compounds

I were mainly interested in the interaction between constituent position and compound headedness, which resulted to be highly significant. Patients are more impaired in retrieving the head constituent, in comparison to the modifier. However, this effect is much bigger when naming head-final compounds than when naming head-initial compounds (6% vs. 15%), as shown in Figure 3.1. The effect of age of acquisition is also significant, indicating that constituents are easier to retrieve when belonging to compounds acquired earlier.

DISCUSSION

In this study I analysed the naming performance of compound nouns in a large group of patients affected by aphasia. The purpose of the experiment was to investigate whether the head-modifier structure of compounds influence word retrieval, and in particular it was aimed at disentangling the effect of constituent position (first vs. second) and constituent role (head vs. modifier). 91 patients participated in the study on the basis of a disproportionate impairment in naming complex nouns in comparison to simple nouns.

Participants' impairment affected more the retrieval of modifier rather than head constituents, but this was mostly observed in head-final compounds; the accuracy for either constituents was similar in head-initial compounds. The different performance in relation to compound headedness is in line with the priming effects observed on normal subjects, and described in Chapter 2. In fact, comparing those effects (Figure 2.1) to the accuracy in naming (Figure 3.1), it is evident that the two patterns of results are extremely similar.

Both priming facilitation and patients' accuracy are measures reflecting the ease of access to constituent representations. Following this line of reasoning, the results of both studies indicate that only in head-final compounds the head is easier to access in comparison to the modifier. In line with the theory proposed by Williams (1981), the head-final structure seems to be preferred in the mental processing of compound words. The right-hand head rule seems to be not only a linguistic theoretical principle, but also a general psycholinguistic property of the mental lexicon: the head-final structure is assumed as the default organization of morphologically complex words.

The results of this experiment are not a mere replica of the findings described in Chapter 2. First, in the present study I employed a set of compound stimuli, which was different from the set used in the psycholinguistic experiment. This difference strongly supports the reliability of the observed effect, and rules out that the phenomenon may simply emerge because of an unfortunate selection of experimental stimuli. Second, the very same effect was observed in two different tasks: in the psycholinguistic study, a lexical decision was requested, thus tapping into the input stages of lexical processing; in the present experiment, patients were asked to name objects on the basis of pictures/definitions and thus relied on output procedures. This converging evidence is a clue about which level of representation generates the observed effect; in fact, a same level has necessarily to be involved in both tasks. The most likely explanation is that the information about a compound structure is stored at central and amodal processing levels; the lemma level of (Levelt et al., 1999) is the best candidate in order to account for the headedness effect, since it represents the grammatical (and some of the semantic) properties of words. Alternatively, or in addition, the semantic system itself could be involved; the conceptual combination between constituents (Gagné & Spalding, 2009) takes place at this level, and the procedure has to be driven by previous knowledge about how constituents are combined (i.e., which constituent is head and which is modifier).

The involvement of the lemma representations is in line with the model proposed in Chapter 1. How compounds are represented at the lemma level will be further investigated in the next Chapter. Conversely, I have not yet considered the role played by the semantic properties of the compound. This will be the central issue of the last two Chapters of this thesis.

Chapter 4:

The multiple lemma representation of verb-noun compounds: a single-case study on deep dyslexia.

The studies presented in the previous chapters have shown that the hypothesis of a compound lemma node is in line with the evidence emerging from both psycholinguistic and neurolinguistic investigations. However, it still unclear whether the activation of the constituent lexemes spreads directly from the compound node, or is rather mediated by the constituent lemma nodes. This latter hypothesis was described by Levelt et al. (1999) in terms of multiple-lemma representation, and is also in line with the superlemma theory proposed by Sprenger et al. (2006).

In the present study the possibility of a multiple-lemma representation was explored by investigating the reading performance of GR, a deep dyslexic patient. Deep dyslexia is a reading impairment characterized by the inability to read non-words, and by the production of morphological, visual and semantic errors when reading existing words, as well as grammatical class (part of speech) effects (Coltheart, 1980). The dual-route reading model (Marshall &

Newcombe, 1973) indicates the grapheme-to-phoneme conversion module as the principal locus of the disorder. However, there must also be a defect along the direct, lexical non-semantic route if semantic effects are to be observed (Shallice & Warrington, 1980). It has also been surmised that there could be additional damage along the semantic route, which could affect either the access to the conceptual system, or the lexical retrieval process, or both. However, the main interpretation indicates impaired control of the information flow between the conceptual system and the phonological output lexicon (Shallice & Warrington, 1980): in other words, according to this hypothesis, deep dyslexia patients can only read through the lexical-semantic pathway, but are nevertheless impaired in retrieving the correct phonological representation at the output level (for another explanation of the reading disorder, see Buchanan, McEwen, Westbury, & Libben, 2003, and Colangelo & Buchanan, 2007). Given its peculiarities, deep dyslexia has already proved to be an ideal experimental model to test the representation of morphology within the mental lexicon (Luzzatti et al., 2001). This is particularly true when investigating the organization of the lemma level, which is assumed to intervene the conceptual system and the phonological output lexicon.

The present work adopts the single-case experimental paradigm, describing the performance of GR to test the multiple-lemma hypothesis regarding the representation of compound words. GR’s performance was assessed on three reading experiments; if the multiple-lemma hypothesis is valid, I would expect grammatical properties of both the compound and its constituents to influence GR’s reading performance under different conditions. In particular, I would expect to find an effect of the constituent grammatical classes when reading verb-noun compounds, due to the access to constituent lemma nodes (Experiment 1). However, it is to be expected that these effects will be less evident in sentence reading tasks, in which the lexical properties of whole compounds (and thus their lemma nodes) are prompted by the syntactic context (Experiment 2). Finally, I considered whether an effect of constituent position could explain the observed phenomena; this was analysed by examining the reading performance for noun-noun compounds (Experiment 3).

Case description and baseline assessment

At the time of the experiment, GR was a 34 year old native Italian speaker; she was a former office worker with a high-school level education whose previous reading and spelling abilities were within the norm. Twenty-four months before the examination she had suffered cerebrovascular damage caused by the rupture of a cerebral aneurysm. A CT scan revealed a left fronto-temporo-parietal lesion.

A language examination (Italian version of the Aachen Aphasia Test, AAT, Luzzatti et al., 1996) revealed a severe Broca aphasia with agrammatic output. Spontaneous speech was scarce, composed of one- or two-word clauses with constant omission of function words. Verbs were also frequently omitted or in non-finite form. Connected speech was also typified by severe anomia and frequent semantic substitutions. Reading was moderately impaired, while repetition and confrontation naming were less affected.

Lexical decision

In a lexical decision task of 72 existing words and 72 non-words, GR recognized accurately 95% of words and 86% of non-words on written input and 95% of words and 84% of non-words on oral input. The high-level performance in these tasks suggests that GR’s visual and phonological input lexicons were relatively unimpaired.

Word comprehension and semantic processing

Written word comprehension was assessed by means of the subtest of the AAT (Luzzatti et al., 1996), in which a word is presented and the patient has to indicate the corresponding figure among four alternatives (the target picture and three foils). GR’s comprehension impairment appeared to be mild (against the normative data of the test). These results indicate a limited impairment of the lexical semantic abilities, and particularly a relatively spared access to word meanings on written input.

A semantic judgment task was used to further assess her processing of written words. A list of 172 words was employed, each of which could belong to one of six different categories (animals, foods, clothes, colours, body parts, musical instruments). Targets were presented tachistoscopically (presentation time: 800ms), and on presentation of each stimulus GR was asked whether it belonged to a specific category (e.g., “Is it something you can eat?”). GR answered correctly in 95% of the trials, indicating that her semantic processing was spared and that her difficulties were mainly caused by the output processing levels.

Picture naming

A picture-naming task of 50 objects and 50 actions (Crepaldi, Aggujaro, Arduino, Zonca, Ghirardi et al., 2006*)* was also used to assess GR’s condition*.* Pictures eliciting nouns and verbs were presented in separate sessions. She named correctly 70% of the nouns and 20% of the verbs, showing a disproportionate impairment in naming verbs compared to nouns ($\chi^2(1)=25.3$, $p<.001$). The results indicate impaired lexical retrieval at the output level, characterised by prominent grammatical class effects.

This grammatical effect is also evident when GR attempted to name verb-noun compound words. In the compound-naming subtest of the Italian version of the AAT she successfully retrieved 100% of the noun constituents, but only 60% of the verb constituents, a confirmation of the effect observed by Semenza et al. (1997) and Mondini et al. (2004).

Reading aloud

The baseline reading-aloud assessment comprised 60 content words, 20 function words and 30 non-words. Content words were sub-divided into 20 high-frequency concrete words, 20 high-frequency abstract words and 20 low-frequency concrete words in order to test for frequency and concreteness effects. The sub-list of high-frequency concrete nouns was taken as the reference set: each of the other lists was matched with this set for length and for the remaining variables, making it possible to assess the effect of word frequency, imageability and grammatical class. Content and function words were presented in a randomized order and separately from non-words. GR’s performance is summarized in Table 4.1. GR was completely unable to read function words and non-words. She performed better on reading content words, but errors were differently distributed across sub-lists: she found concrete nouns easier to read than abstract nouns; however no effect of word frequency emerged. A logistic regression on accuracy revealed no length effect.

	High Freq. Concrete Nouns	**Low Freq. Concrete Nouns**	**High Freq. Abstract Nouns**	**Function Words**	**Non-words**
N	20	20	20	20	30
Correct	15	15	8	0	0
$\chi^2_{(1)}$	baseline	0 n.s.	5,01 *	5,71 *	8,33 *
Visual errors	1	1	2	5	0
Morphological errors	2	1	0	0	0
Semantic errors	2	2	2	0	0
Visual errors	1	1	2	5	0
No-response	0	1	8	15	6
L-by-L reading	0	0	0	0	24

Table 4.1: Analysis of reading errors in the baseline assessment: visual errors, morphological errors, semantic errors, no response and letter-by-letter reading attempts (L-by-L). Statistical tests for the considered effects (in comparison with high-frequency concrete words) are also reported.

GR's reading errors were further classified through a qualitative analysis. She made visual (e.g., *affatto* [at all] → *affitto* [rent]), morphological (e.g., *libreria* [bookshop; lit. bookery] → *libro* [book]) and semantic errors (e.g., *secchio* [bucket] → *pozzo* [pit]). Moreover, she was completely unable to retrieve a number of stimuli (no-response), and occasionally adopted a slow reading strategy, first spelling out (mostly correctly) each individual letter and then combining them in a unique (and mostly erroneous) phonological string. This arguably indicates letter-by-letter reading attempts (Patterson & Kay, 1982), which emerged only for non-words. Errors were differently distributed in the word stimuli classes. While no dominant error types emerged for concrete words, abstract and function words mainly elicited no responses. For these latter classes of stimuli, visual errors mainly consisted of concrete content words (*guaio* [trouble] → *guanto* [glove]; *oltre* [beyond] → *otre* [wineskin]).

GR's performance on this test is compatible with a deep-dyslexic disorder. Concreteness, lexicality and grammatical class effects emerged, in line with a predominant use of the lexical-semantic route. She adopted a letter-by-letter reading strategy when the lexical route failed to function (i.e., when reading non-words), which suggests that she is implicitly able to discriminate between lexical and non-lexical material: she did not use the letter-by-letter reading strategy when reading words, not even function words and abstract words, where she opted not to respond rather than to use the letter-by-letter strategy. As this occurs consistently with her good performance on lexical decisions, semantic judgments and written word comprehension, it points to a deficit at output level: written words can be identified in the input lexicon, but the retrieval of their phonological representation is impaired (for a similar case, see Laine, Niemi, Niemi, & Koivuselkä-Sallinen, 1990). GR's disorder arguably arises between the semantic system and the output lexicon.

Reading of morphologically complex words

Three parallel reading tasks were administered to evaluate the extent of GR's morphological disorder. In the first task, 46 nouns were presented both in the singular (*cappell**o***, [hat]) and the plural (*cappell**i***, [hats]) form (total: 92 items). In the second task, 32 verbs were presented in their thematic form (*ama*, [he/she loves]), the infinitive (*amare*, [to love]) and a finite form (*amavi*, [you loved]) (total: 96 items). In the third task, 27 adjectives were presented, either in the non-marked form (masculine singular, e.g., *car**o*** [dear$_{m,sg}$]) or inflected for the feminine gender and/or in the plural form (*car**a***$_{f,sg}$, *car**i***$_{m,pl}$, *car**e***$_{f,pl}$). In each task the differently inflected forms were matched for form frequency and length (with the exception of the verb theme (*ama*, [he/she loves]), which was necessarily shorter than the other verb forms).

The same pattern of results emerged in the three tasks: GR performed better on reading the base form than the marked word forms, i.e., she read singular nouns better than plural nouns (63% vs. 41%; $\chi^2(1)=4.34$, $p<.05$), thematic forms of the verb better than either the infinitive or a finite form (31% vs. 9% vs. 0%; $\chi^2(2)=14.06$, $p<.001$), singular-masculine forms better than other adjective forms (48% vs. 19%; $\chi^2(1)=5.33$, $p<.05$). These results indicate an impairment in combining components of morphologically complex words (De Bleser & Bayer, 1990; Luzzatti et al., 2001).

Verb-noun dissociation in reading

GR's performance on the preceding reading tasks was also analyzed to test for verb-noun dissociation, comparing the word reading aloud performance on nouns (see 2.2) with that on verbs (see 2.3). It emerged that she read nouns significantly better than verbs (63% vs. 13%; $\chi^2(1)=41.6$, $p<.001$). This effect may depend on the different morphological richness in the two groups of stimuli: Italian verbs have complex paradigms and can take as many as fifty different inflectional suffixes, while nouns are inflected for number only (singular and plural); therefore it could be more difficult to retrieve a inflectional verb suffix given the vast range of alternatives. However this alternative interpretation is not supported by further analyses: the result emerges (63% vs. 31%; $\chi^2(1)=9.3$, $p<.01$) even when comparing nouns to verbs in the thematic form (the base – and easiest to retrieve – verb form, for which a suffix selection is not required). The result does not depend on either frequency, imageability or length: the dissociation also occurs in a logistic regression analysis (B=-1.09, z=2.14, $p<.05$) including length, imageability and word frequency as covariates. These results indicate a grammatical class effect, independent of morphological complexity and other variables.

Experiment 1

In the first experiment I tested whether constituents are retrieved in isolated compound reading. As explained in the introduction, in picture naming tasks patients affected by agrammatism often make more errors on the verb constituent of VN compounds, which are globally nouns (Semenza et al., 1997; Mondini et al., 2004). This result has been interpreted as an evidence in favor of the routine (de)composition of compound words. However, it is at odds with results obtained on reading experiments, which suggest direct access to compounds (Behrmann et al., 1990; Mondini et al., 2002). This leads to the question of whether the effect reported by Semenza et al. (1997) and Mondini et al. (2004) in picture naming could be due to specific task demands, and so might not be replicated in reading tasks. In this experiment I examined GR's performance on reading VN compounds, considering also her reading performance on the individual constituents presented in isolation. If regular access to constituents takes place, a similar error distribution for verbs and nouns in the two conditions would be expected. The results will be discussed in terms of word production, since GR's impairment mainly affects the output levels of the reading process.

Materials and methods

Fifty-seven Italian VN compounds were used as experimental stimuli. Verb-noun combinations are the most productive form of compounding in Italian; they are usually composed of a verb and its direct object: for example, *aspirapolvere* (*vacuum-cleaner*) literally means *inhale-dust*. Verb-constituents that are homographs to nouns (as for example *portamonete*, purse, lit. *carrycoins*, where $porta_V$ is homograph to $porta_N$, door) were not used; in other words, the first constituent was always unambiguously a verb. All the compounds were concrete words, mainly referring to objects and people. The verb and noun constituents were matched listwise for stem frequency and length. Information about word frequency was obtained from the COLFIS corpus (Laudanna et al., 1995). The individual constituents were given in a parallel list for a total of 114 simple-word stimuli (57 verbs and 57 nouns). The two sets (compounds and individual constituents) were presented in two separate sessions to prevent priming effects. GR was asked to read the written stimuli aloud. Answers were considered valid only if given within five seconds from item presentation; lexical repairs and longer latencies were considered as errors. A qualitative analysis of the performance in compound reading was also done to assess a selective impairment in retrieving the verb constituents of the VN nominal compounds.

Results

When the constituents were presented in isolation, GR read nouns better than verbs (63% vs. 12% correct; $\chi^2(1)=26.2$, $p<.001$). When asked to read VN compounds, she made roughly the same number of errors on the compound stimuli as on the verbs presented in isolation (16% vs. 12%; $\chi^2(1)=0.35$, n.s.). On the contrary, her performance on reading VN compounds was significantly worse than for the isolated noun constituents (16% vs. 63%; $\chi^2(1)=26.1$, $p<.001$).

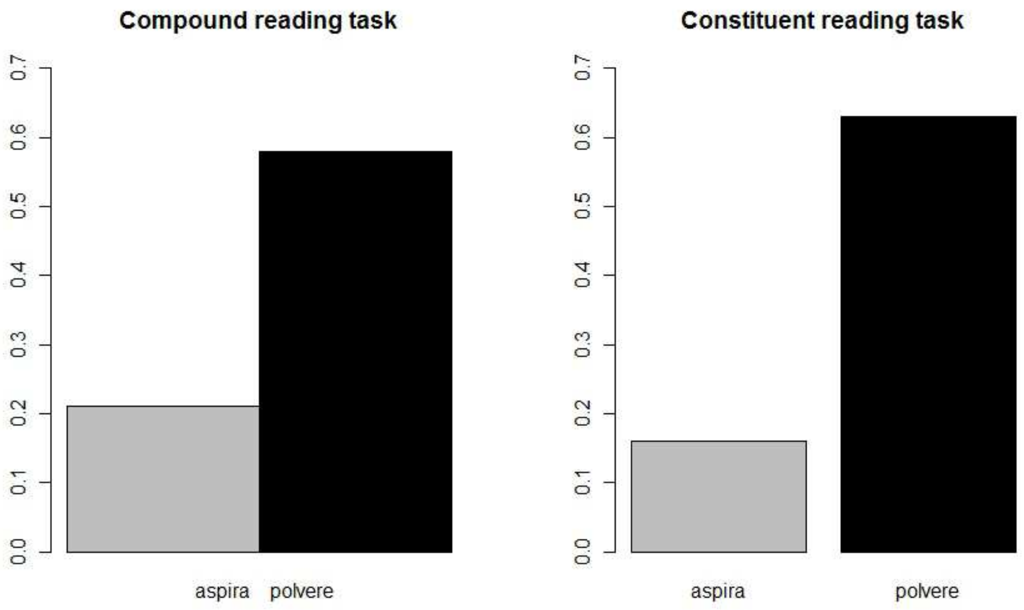

Figure 4.1: accuracy in reading aloud verbs and nouns, either as constituents of VN compounds (a) or in isolation (b). *aspira* = inhale/suck up; *polvere* = dust.

The errors in compound reading were mostly no-response or omissions/substitutions of either constituents. When the patient made substitutions, it was mostly with another word of the same grammatical class. Errors were made more frequently on the verbal than the nominal constituent (21% vs. 58%; $\chi^2(1)=16.2$, $p<.001$), in a rate similar to that which emerged in the individual presentation (12% vs. 63%; see Figure 4.1).

Discussion

These results indicate that VN compounds, albeit they are globally nouns, are as difficult to read as their verb constituents presented in isolation. This phenomenon is due to difficulty in retrieving verbs also when they are embedded in compounds: in fact, the qualitative analysis of the compound reading performance indicates that errors mainly affect the verb constituents. This replicates the effect observed by Semenza et al. (1997) and Mondini et al. (2004) in picture naming, thus ruling out task specific effects, and clearly indicating that grammatical properties of constituents are accessed when reading compounds, supporting a model of compound production in which constituents are separately processed. In the theoretical framework I adopted, this effect arguably arises at the lemma level; in other words, it depends on the constituent lemma nodes being activated when reading compounds. This conclusion follows directly from the effect being related to the grammatical class of the constituents, since the syntactic properties of words (grammatical class information) are stored in their lemma representations. GR, suffering from disproportionate impairment in reading verbs, is not able to access the verb-constituent nodes.

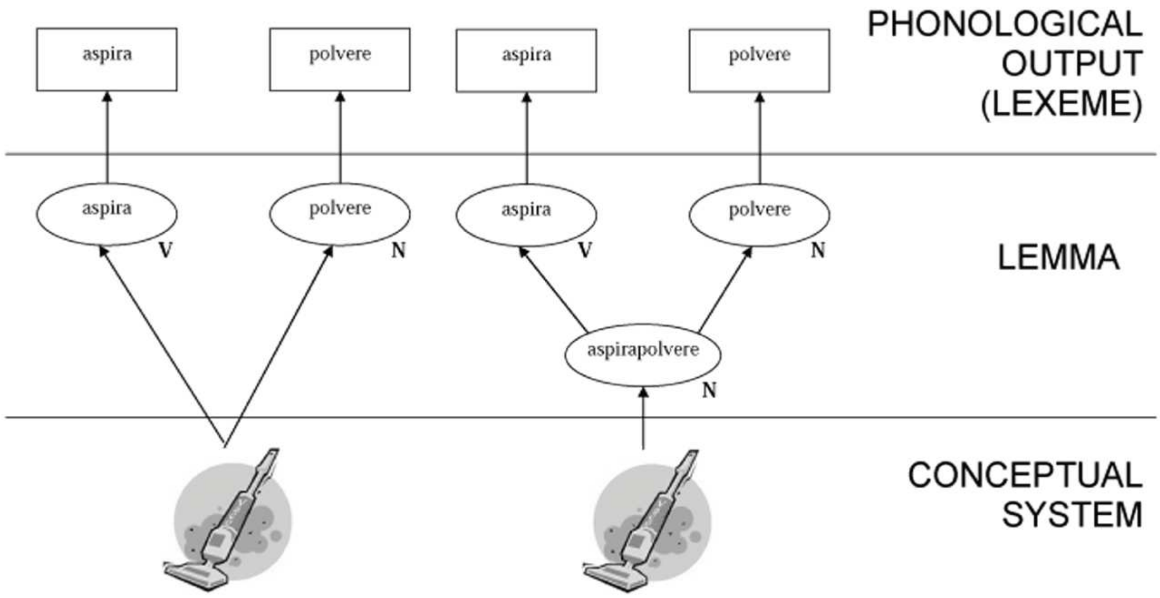

Figure 4.2: Alternative representations of VN compounds: (a) only constituent nodes are represented at the lemma level; (b) the compound and its constituents have their own representation at the lemma level.

However, the present data also indicate that the error rate for verbs and nouns does not change when comparing compounds to their constituents presented in isolation; in other words, GR produced the same pattern of errors, irrespective of whether the verbs and nouns were presented as stand-alone words or as embedded in a compound (see Figure 4.1). This is even stronger proof of a regular (de)composition of compounds, suggesting that access to constituents is mandatory in compound processing, and that the constituents are retrieved as independent words: constituent nodes would be therefore the ultimate building blocks of a compound representation. This can potentially mirror two alternative lemma architectures (see Figure 4.2). Compounds could be represented through a multiple-lemma structure (Figure 4.2b) in which the access to the lemma constituent nodes is mandatory but follows the activation of the whole-compound lemma-node, activated in turn by the conceptual representation of the object denoted by the compound. Alternatively, the conceptual representation of the compound could directly co-activate the constituent lemma nodes (Figure 4.2a): in this case, VN compounds would be represented at lemma level as two syntactically related separate nodes, without an explicit representation of the whole compound. While this latter hypothesis is computationally more economical, positing fewer processing units, the multiple-lemma hypothesis seems to be more in line with theoretical considerations. In fact, the grammatical and semantic traits of the compound do not directly depend on the properties of the constituents; this is especially true for VN compounds. Take the masculine compound noun *aspirapolvere* (vacuum-cleaner) for example: its grammatical properties – i.e., of being a noun - do not derive from the first constituent *aspira* (inhale/suck up), since it is a verb; the second constituent *polvere* (dust) does not percolate its traits either, as it is a feminine and not a masculine noun. The same consideration applies to the compound meaning: *aspirapolvere* does not describe a sucking action, nor does it refer to a kind of dust; an *aspirapolvere* is an object that sucks up dust. This specific example represents a common occurrence in Italian compounding (for similar considerations regarding English noun-noun compounds see Badecker, 2001). This representation may also explain the qualitative pattern in GR’s errors: while her omissions/substitutions of the individual constituents may be caused by damage to the constituent lemma nodes, no-responses may also depend on an inability to access the compound lemma itself. In the second experiment the multiple-lemma hypothesis was empirically addressed, in an attempt to elicit whole-compound effects through specific conditions.

Obviously, constituent positions could constitute an alternative (and simpler) interpretation of the present results. Indeed, it could be argued that it is impossible to disentangle the grammatical-class effect from a positional effect in VN compounds. Thus, it might be more difficult to retrieve verb constituents because they appear in the first position and not because of their grammatical aspects. This will be addressed in the third experiment.

Experiment 2

The hypotheses which emerged in Experiment 1 were empirically tested in Experiment 2, and in particular whether compound access depends on the activation of the single constituents only, or also depends on whole-compound representations. This latter architecture appears to be most sound for theoretical reasons. Since the compound properties cannot be derived entirely from the constituents by means of rules (see the discussion of the previous experiment), information regarding whole compounds has to be stored in the mental lexicon, arguably at the lemma level. In this experiment, GR's reading performance was investigated, contrasting VN compounds to paired verb phrases, both embedded in a sentence context. If compounds have their whole-word lemma nodes (in addition to the lemmas of their individual constituent morphemes), they should be easier to read than the corresponding verb+object verb phrases, which have to be processed as two independent elements.

Materials and methods

Twenty-five Italian VN compounds and the corresponding 25 verb phrases (composed of the verb + object as two independent words) were used as experimental stimuli. The only difference between the compound stimuli and their paired verb phrases was that the latter were written as two separate words: *guardaroba* (cloakroom, lit. watch-stuff) versus *guarda roba* ([he/she] watches stuff). In Italian, the phonological sequence of the VN compound and of the corresponding V+N verb phrase, as well as the corresponding stress pattern, are identical in the two conditions. Moreover, the verb and noun components were matched for stem frequency and length. The compounds were embedded in sentences, in such a way as to be the direct object of the sentence verb and/or follow a determiner (e.g., *i clienti riempirono il* ***guardaroba*** *in una sola ora*; the patrons filled the **cloakroom** in one hour only): the syntactic context was thus meant to suggest the grammatical class (noun) of the compounds, in order to elicit whole-word effects. The verb phrases were also embedded in sentences, as the verb phrase of a simple matrix clause (e.g., *per tutta la sera Maria* ***guarda roba*** *indecente in TV*; for all the evening Mary **watches** trashy **stuff** in TV). Compounds and paired verb phrases occupied roughly the same visual position (i.e., central) in the sentence. The 50 sentences were presented in a pseudo-randomized order, so that in half of the stimuli the compound condition was administered first, and vice-versa for the other half. GR was asked to read the sentences aloud. Both her performance on the whole V+N sequence (compounds vs. verb-phrases) and her errors on the individual components (verbs vs. nouns) were computed. Lexical repairs were counted as errors. In order to check the reliability of these results, GR was given the task again after a period of one month.

Results

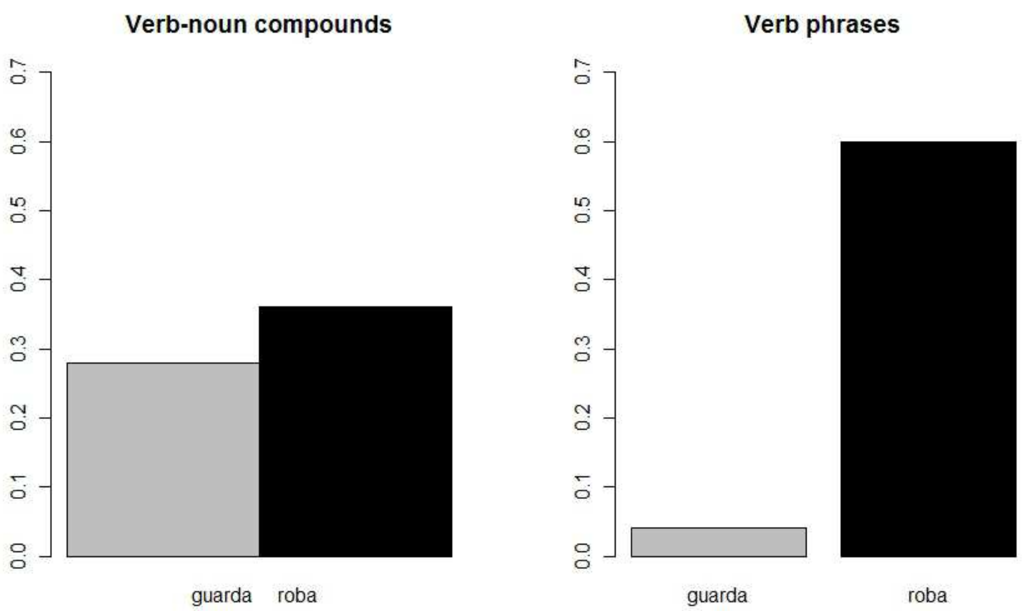

Figure 4.3: Reading-aloud accuracy of Nouns and Verbs in a sentence context: (a) verb- and noun-constituents of VN compounds; (b) verbs and nouns in verb phrases; *guarda* = watch; *roba* = stuff.

When the VN compounds were embedded in sentences, GR read them better than the corresponding verb phrases (24% vs. 4%; $\chi^2(1)=4.15$, $p<.05$). Her poor performance on verb phrases is mainly due to her greater difficulty in retrieving verbs as opposed to nouns (4% vs. 60%; $\chi^2(1)=18.01$, $p<.001$). The same consideration does not apply to compounds: her retrieval of the verb and the noun constituent was almost equally accurate (28% vs. 36%; $\chi^2(1)=0.36$, n.s.; see Figure 4.3) . From a qualitative point of view, she tended either to read the whole compound (24%), or not to read it at all (64%). The re-test confirmed the results obtained in the first analysis: GR read compounds better than verb phrases (48% vs. 8%; $\chi^2(1)=9.92$, $p<.01$), and the grammatical class effect emerged in phrases (24% vs. 52%; $\chi^2(1)=4.16$, $p<.05$) but not in compounds (60% vs. 68%; $\chi^2(1)=0.34$, n.s.).

Discussion

The hypothesis emerging from the first experiment, indicating that VN compounds may be retrieved through the separate representations of their constituents (similar to verb phrases), was tested in the second task. In fact, the hypothesis was not empirically supported: VN compounds are easier to retrieve than paired verb phrases, despite the orthographical and phonological identity. This difference can only be explained by assuming that VN compounds are also represented as whole-word units and are thus facilitated in comparison to verb phrases, which necessarily lack a unique representation. The present results are in line with the – theoretically supported - hypothesis of a multiple-lemma representation.

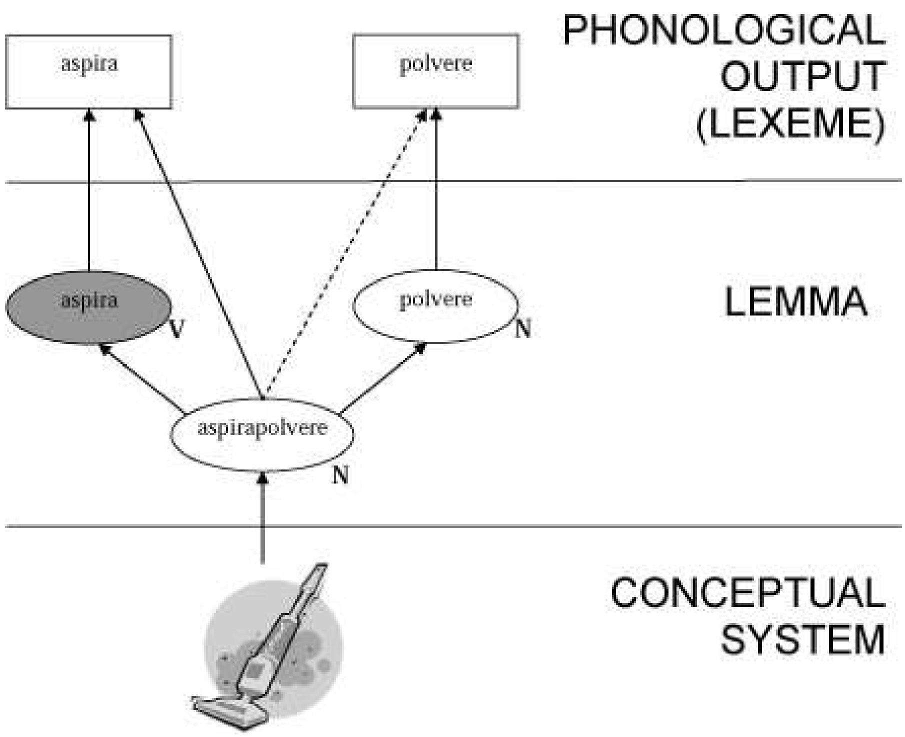

Figure 4.4: The syntactic context modulates access to compounds: verb nodes (in grey) are inhibited and activation can thus spread from the compound lemma node directly to the lexeme level, accessing the constituent lexemes

GR's performance also provides information about how this effect could emerge in the lemma-lexeme framework. The results indicate that the grammatical class effect in reading VN compounds (see Experiment 1) disappears when compounds are embedded in a sentence context: GR omitted in this case the verb constituent as frequently as she omitted the noun constituent. This result seems to depend on the contextual facilitation of the syntactic frame: since the compound is the object of a verb, it is expected to be a noun; the verb-constituent lemma nodes are thus likely to be inhibited during reading, and activation arising from the whole-word representation can bypass them and directly activate the lexeme representations (Figure 4.4).

The results cannot be explained by a task difficulty effect. In fact, when GR read compounds in a sentence context, her performance was better than in the control condition, while her performance deteriorated when reading compounds presented in isolation. The separation of the phrase elements (in comparison to the compound constituents, which are written together) is not crucial either: her performance on verb phrases was qualitatively similar to that on compounds in the first experiment. It is thus the syntactic cue by itself that determines GR's performance in Experiment 2. The results rule out the hypothesis of a mandatory access to the lemma nodes of the constituents, indicating that the activation of their syntactic properties can be modulated by contextual information. The contrasting results of Experiment 1 are arguably due to the compound stimuli being presented as isolated words; in fact, an overgeneralization of a (de)compositional procedure may emerge (a well-known effect in psycholinguistics, see Andrews, 1986), especially when the experimental list is composed of complex words only: morpheme-related (de)compositional effects (e.g., constituent frequency) can be enhanced vis-à-vis the normal reading procedure. Importantly, the present data are in line with previous studies reporting whole-word effects in compound processing: in the experiments by Mondini et al. (2002), whole-word effects mainly arose when compounds were presented in a sentence context; it could be argued that also in this case the context was crucial in activating a whole-word representation of the compound.

From a qualitative point of view, GR either retrieved the whole compound or completely omitted it. This phenomenon suggests that, once eliminated the source of difficulty related to verb retrieval, GR's impairment mainly affects the activation of the whole-word node: once it has been accessed, the compound is relatively easy to read.

Experiment 3

The results of Experiment 1 and 2 were interpreted in terms of grammatical-class effects, but might also be determined by constituent-position effects, since in VN compounds the verb is always the first constituent. The aim of this experiment is to discriminate between grammatical-class and constituent-position effects, i.e., to assess whether the constituent-position effect still emerges once the grammatical-class confounding is ruled out.

Materials and Methods

Forty-eight Italian nominal compounds were used as experimental stimuli. In order to avoid the results being influenced by GR's impairment for verbs, only noun-noun (NN), adjective-noun (AN) and noun-adjective (NA) compounds were used (35 NN, 6 AN, 7 NA). The stimuli were either right-headed (24) or left-headed (24) compound nouns; the first and second constituent were matched for stem frequency and length.

GR was asked to read the compound nouns aloud. Responses were considered valid only if given within five seconds from item presentation; lexical repairs and longer latencies were counted as errors. Errors on the individual constituents were also computed in order to investigate position effects.

Results

GR read 33% of the compound nouns correctly. A by-position analysis indicates correct retrieval for 54% of the constituents in the first position and 50% of the constituents in the second position. The difference was not significant ($\chi^2(1)=0.17$, n.s.).

Discussion

Since there is no difference in the error rate between the first and the second constituents, the results indicate that constituent position does not influence GR's ability in retrieving constituent representations. This would suggest a parallel access to constituent nodes. Therefore, the results of Experiment 1 cannot be explained in terms of positional effect, indicating the reliability of the grammatical-class effect observed in Experiment 1.

General discussion

This study investigates the mental representation of compound words through the reading performance of GR, a patient suffering from deep dyslexia. Three compound-noun reading experiments were conducted. The results indicate that, when reading a VN compound the verb constituent is more difficult to retrieve than the noun constituent. However, this effect can be modulated by changing the experimental condition: when compounds are embedded in a sentence, both constituents are retrieved with the same level of accuracy. The effects are due to the grammatical class of the constituents, and not simply their relative order.

Considered together, the results from these experiments suggest a complex representation of compound words in the mental lexicon, in which both whole-compound and constituent properties play a role. Since the observed effects are related to the grammatical properties of the lexical elements involved, this complex interaction arguably takes place at a level where this kind of information is represented, i.e., the lemma level in Levelt et al.'s theory (1999). The results are thus in favor of a multiple-lemma representation of compound words. However, the interplay between the lemma nodes involved in the compound representation is highly dynamic, and can be influenced by the contextual information of the various experimental conditions (isolated vs. sentence-embedded presentation). For this reason a "superlemma" representation (as proposed by Sprenger et al, 2006) does not completely fit the findings in GR's case: a "superlemma" would lead to mandatory activation of other lemma nodes, but the present data show that under particular conditions a compound lemma representation can directly activate the corresponding constituents at the lexeme level. In other words, the various units are not arranged in a strict hierarchy; the representations of both the compound and its constituents are linked via a complex interaction spanning through the lemma and the lexeme level. On the contrary, this type of interaction is in line with the principle of maximization-of-opportunity, a theory proposed by Libben (2006) to explain the processing of compound words. According to this hypothesis, all available information (including constituent properties) is exploited when processing a compound, which results in a redundant and multi-componential system as the one described above. This flexible architecture would be particularly evident in tasks with minimal contextual information (such as lexical decision or single-word reading). In fact, in such tasks, Libben's principle would maximize the probability of success of an unimpaired cognitive architecture, which is able to fully exploit all the information contained in the compound. However, the results of Experiment 1 indicate that GR's performance might be hampered by this normally adaptive procedure due to her disproportionate impairment in reading verbs; automatic access to verb constituents makes it impossible to produce the (nominal) VN compounds. The apparently conflicting results found on reading compounds embedded in sentences (Experiment 2) are arguably due to the different demands of the tasks involved. Indeed, in this condition the reader enacts a more natural behavior, reading well-formed sentences for comprehension. This triggers incremental processing in the sentence context: the first words met influence the processing of those that follow and the equilibrium between lemma nodes is continuously reorganized as each word is read. In particular, we expect to find a noun after a determiner or a verb; in computational terms, in this context verb nodes would be inhibited by the previous syntactic encoding. In Experiment 2 a verb and/or a determiner preceded all VN compounds, which were therefore processed as simple nouns: as the verb nodes were inhibited, the activation was able to spread directly from the compound lemma to the constituent lexemes, with the result that GR's performance improved when reading compounds embedded in sentences.

The observed effects are not easily implemented in purely full-listing models. In fact, if compounds were stored as a whole in the phonological output lexicon (e.g., Caramazza, 1997; Janssen et al., 2008), the grammatical class of the constituents would not play any role in compound retrieval. Parallel-route models (e.g., Pollatsek et al., 2000) cannot easily account for these effects either since, (i) the (de)compositional route would be hampered by the grammatical class effect affecting the verb constituent and (ii) the parallel whole-word route should still lead to correct reading of nominal compounds, which actually is not the case. However, parallel-route models can be adapted to explain the present results, assuming that experimental conditions can modulate the relative efficiency of the processing routes: compound words in isolation would force access to constituents, and thus reveal the patient's verb impairment.

The results of this study were obtained by examining the reading performance of a patient affected by deep dyslexia. The experimental design adopted was crucial to obtain information about morphological processing (for a prior example, see Luzzatti et al., 2001): deep dyslexia, due to the impairment affecting sub-lexical reading, is an ideal condition for investigating the architecture of the mental lexicon.

Chapter 5:

Frequency effects and the conceptual combination of compound constituents: the role of semantic transparency and headedness.

In the first four chapters, we investigated the representation of compound words, especially in relation to compound headedness. However, in the previous studies the role played by semantics in the processing of compounds has been ignored. This issue is closely related to that of semantic transparency, which has been shown to modulate the lexical access to constituents (e.g., Sandra, 1990; Libben et al., 2003). In the present study I investigated the role of headedness and semantic transparency by studying frequency effects in Italian compound processing in a lexical decision task of compound nouns.

Constituent frequency effects were considered diagnostic of the ease of access to constituent meanings (Gagné & Spalding, 2009) for the purpose of studying the semantic processing of compound words. Working on this assumption, the interactions between constituent frequencies, headedness and semantic transparency were the principal effects to be considered. In fact, larger frequency effects in transparent compounds for both constituents were expected, due to their close relations with the compound meaning; however, information regarding the head-modifier structure is also necessary in order to combine the constituent meanings. We therefore expected compound headedness to modulate constituent frequency effects also. If our hypothesis of a default search for the head in the final position (Chapter 2 and 3) is correct, the headedness modulation should mainly affect the second constituent, i.e., we would expect a difference between the frequency effects of the head and the modifier for the second constituent only. If, on the other hand, this difference were to appear for both constituents, this would support an effect of the head-modifier structure independent of the constituent position.

Materials and methods

Participants

Forty-two neurologically intact, right-handed subjects participated in the experiment (mean age = 23±3, mean education = 18±3). All were native Italian speakers with normal or corrected-to-normal vision and no developmental reading disorders; they were attending the University of Milano-Bicocca as either undergraduates or postgraduates, and participated in the study in exchange for credits or as volunteers.

Materials

Independent variable	Mean (S.D.)	Median	Min	Max
Compound Surface Frequency	7 (11)	3	0	63
Compound Lemma Frequency	7 (12)	3	0	63
1st constituent Surface Freq.	266 (301)	152	1	1018
1st constituent Lemma Freq.	399 (444)	197	3	1653
2st constituent Surface Freq.	194 (367)	77	0	2159
2st constituent Lemma Freq.	260 (422)	113	1	2193
Compound Semantic Transparency	.49 (.28)	.50	.4	.94
1st constituent ST	.57 (.27)	.57	.02	.94
2nd constituent ST	.57 (.24)	.60	.08	.92
Length	10 (1.4)	10	8	13
1st constituent length	5 (.7)	5	3	7
2nd constituent length	5 (1.1)	5	4	8

Table 5.1: Summary of the independent variables; frequency values are based on the COLFIS corpus (out of 3,800,000 word forms; Laudanna et al., 1995).

Forty-eight endocentric nominal compounds were selected as target words. Thirty-four stimuli were noun-noun (NN) compounds. As in Italian NN compounding is not as productive a process as it is in the Germanic languages, compounds with a similar structure (seven noun-adjective - e.g., *camposanto*, graveyard, lit. field+holy - and seven adjective-noun compounds - e.g., *altoforno*, blast-furnace, lit. high+oven) were included in order to obtain a sufficiently large sample of head-initial and head-final nominal compounds. Half of the stimuli were head-initial (e.g., *pescespada*, swordfish, lit. fish+sword) and half were head-final (e.g., *astronave*, starship)

Several psycholinguistic variables were considered for each stimulus (see Table 5.1). These included surface and lemma frequency of the whole compound and of its constituents, number of letters and semantic transparency. Frequency values were collected employing the COLFIS corpus (Laudanna et al., 1995) and were logarithmically transformed in order to reduce the skewness of the distribution.

Frequency effects are not always linear (e.g., Bien, Levelt & Baayen, 2005), and thus matching for mean frequency may not be sufficient to prevent the emergence of confounding effects related to potential strategies automatically adopted by the participants: for example, if the frequency of the first constituents is consistently higher than that of the second, the former could attract much more attention and artificially magnify first-constituent frequency effects. In the employed stimuli, both log-transformed surface frequency and lemma frequency distributions of the first and the second constituent are matched (two-sample Kolmogorov-Smirnov tests were not significant). However, matching could not be achieved for the whole compounds, whose frequency levels are significantly lower than those of the constituents. Surface frequency was defined as the frequency of the single word form, while lemma frequency was computed as the sum of the frequencies of all the possible inflectional forms of a given word: e.g., if surface frequency was the frequency of *want,* lemma frequency was the sum of the frequencies of *want*, *wanted*, *wants*, *wanting*. Surface frequency values were employed as frequency measures in the analyses[3].

[3] Analyses employing lemma frequency in place of surface frequency measures led to comparable results.

Two different semantic transparency measures were considered (see discussion above). The semantic transparency of the whole compounds (Ji, Gagné & Spalding, 2011) was evaluated by 25 undergraduate students in a preliminary study: the participants were asked to rate each compound on a four-point rating scale ranging from “very unpredictable” to “very predictable”, according to the extent to which its meaning could be predicted from the meaning of the underlying constituents. Mean semantic transparency values were then converted to percent values (ranging from 0 to 1). The semantic transparency of the constituents was evaluated applying Libben et al.’s (2003) procedure: 20 undergraduate students were asked to rate the constituents of each target compound separately, evaluating the extent to which their meaning contributed to the meaning of the whole compound. A four-point rating scale was employed, and mean semantic transparency values were converted to percent values. All predictors were mean-centred to ensure a more reliable estimation of the parameters in the subsequent analyses (Kraemer & Blasey, 2004).

Head-final and head-initial compounds were matched for semantic transparency and lemma and surface frequency of both compound and constituents, but differed slightly in length (9.7 vs 10.6 letters, $t(46)=2.3$; $p=.03$). The lengths of both the first and the second constituents were also matched. As first constituent transparency measure was correlated to the compound transparency measure ($r=.52$), the variables finally introduced into the study were the residuals of the first-constituent transparency regressed on the compound transparency, following Kuperman et al. (2008).

144 non-words, matched for length with the compound stimuli, were created as targets for the non-word trials. Moreover, in order to avoid list effects triggering an overgeneralization of decompositional processing (see Andrews, 1986), 72 three-to-four syllable monomorphemic real nouns (e.g., *dromedario*, dromedary) were introduced as filler trials. Consequently, complex words were only 18% of the stimuli.

Methods

Participants were tested in a room with dimmed lighting. The stimuli, preceded by a 500ms fixation point, appeared in the centre of a computer screen in white characters on a black 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 (RTs).

The same experimental list, divided into three blocks, was given to all the participants. They were asked to judge whether an upper-case letter string appearing on the screen was a real word or not; the importance of both speed and accuracy was stressed during the instructions. A series of practice trials were run prior to starting the proper experiment, and five trials were inserted at the beginning of each experimental block as warm-up items.

Data analysis

Only correct responses were analysed. Individual datapoints deviating from the normal distribution of data were excluded subsequent to the inspection of qq-plots. The procedure was validated by assessing kurtosis change after the outlier removal (i.e., the Anscombe-Glynn test was not significant after the procedure; Anscombe & Glynn, 1983). RTs were logarithmically transformed to obtain a Gaussian-like distribution and were employed as a dependent variable. Mixed effect regression analyses were carried out taking participants and items as crossed random effects (Baayen et al., 2008).

The choice of employing continuous variables as fixed predictors instead of their dichotomized counterpart was made for both practical and theoretical reasons. In the first place, our aim was to test several psycholinguistic predictors contemporaneously; it was difficult to obtain groups of items which were perfectly matched, given the limited pool of available compound stimuli. In the second place, the methodological literature repeatedly suggests that, when dealing with naturally continuous variables, a continuous indicator outperforms a dichotomized indicator in terms of both statistical power and accuracy of the estimated relations (Cohen, 1983). Moreover Maxwell and Delaney (1993) demonstrated mathematically that dichotomization may inflate Type I error rates, thus potentially leading to incorrect results. Finally, these variables were related to word properties and thus could not be randomly assigned to conditions, so a factorial design would be inappropriate to investigate their effects (Keppel & Zedeck, 1989). These considerations are particularly appropriate to psycholinguistic research, which often deals with naturally continuous latent variables: in other words, there is no such a thing as an infrequent (or frequent) word, words are more or less frequent on a comparative basis; similarly, a continuous gradient of semantic transparency is a better characterization of complex words than various categories of the measure (e.g., “transparent”, “semi-transparent” and “opaque”). Therefore, regression designs are often better than more traditional factorial designs, when investigating psycholinguistic effects (Baayen 2004; Baayen, 2010a). Dichotomizing a continuous variable is justified only in a few, very limited circumstances (DeCoster, Iselin & Gallucci, 2009).

In a first analysis, frequency of the whole compound and of its constituents, length (number of letters), headedness (as a dichotomic variable) and semantic transparency measures were considered as main fixed effects and several interactions were introduced in the model. First, the interactions between the frequency of the two constituents and headedness were introduced to evaluate the effect of the head-modifier structure on compound processing. Second, the length effect on whole-word access (see Bertram & Hyönä, 2003) was assessed by evaluating the interaction between compound frequency and compound length and between constituent frequency values and compound length. Third, the interactions between compound frequency and constituent frequencies were introduced to test the modulation of compound frequency on constituent frequency effects (e.g., Kuperman et al., 2009) and the interaction between the two constituent frequency measures was also tested. Finally, the interactions of the semantic transparency of the compounds with all the effects involving frequency measures were analyzed to evaluate the semantic modulation on constituent and whole-word access (Sandra, 1990). A similar procedure was followed for the constituent transparency measures. The analysis started with a full factorial model which was progressively simplified by removing the variables that did not significantly contribute to the goodness of fit of the model (i.e., the result of the likelihood ratio test comparing the goodness-of-fit of the model before and after removing the effect of each parameter was not significant). Variables were excluded one by one, starting from non-significant three-way interactions, on the basis of the chi-square values associated to the model comparison tests. This procedure was then applied to the two-way interactions and, finally, to the main effects. No effect or interaction was removed from the model if part of a higher-order interaction. Initially, the random-effect structure included the effects of items and participants on the intercept. Moreover, random effects of participants and of items on variables other than the intercept were tested, in order to evaluate whether their inclusion significantly increased the model goodness of fit. The statistical significance of the fixed effects was evaluated using a Markov chain Monte Carlo (MCMC) sampling (Baayen et al., 2008). Once the models were fitted, atypical outliers were identified and removed (employing 2.5 SD of the residual errors as criterion). The models were then refitted to ensure that the results were not driven by a few overly influential outliers. Statistics of the refitted models are reported.

A second analysis, using the procedure adopted for RTs, was carried out with response accuracy as the dependent variable. The probability of answering correctly was studied by means of a mixed-effect logistic model (Jaeger, 2008).

Independent variable	**x < Q1**	**Q1 <x < Q2**	**Q2< x< Q3**	**x > Q3**
Compound Surface Frequency	794	758	710	668
1st constituent Surface Freq.	743	702	730	766
2st constituent Surface Freq.	721	756	756	706
Compound Semantic Transparency	781	747	709	699
1st constituent ST	745	718	764	712
2nd constituent ST	763	741	712	722
Length	703	709	770	809

Table 5.2: Mean RTs (in ms) for different intervals of the independent variables (Q1 = first quartile, Q2 = second quartile, Q3 = third quartile)

Independent variable	**x < Q1**	**Q1 <x < Q2**	**Q2< x< Q3**	**x > Q3**
Compound Surface Frequency	.91	.89	.95	.97
1st constituent Surface Freq.	.96	.93	.91	.92
2st constituent Surface Freq.	.91	.94	.90	.96
Compound Semantic Transparency	.89	.90	.96	.97
1st constituent ST	.90	.94	.93	.94
2nd constituent ST	.93	.90	.95	.93
Length	.91	.95	.92	.95

Table 5.3: Mean accuracy for different intervals of the independent variables (Q1 = first quartile, Q2 = second quartile, Q3 = third quartile)

Results

Tables 5.2 and 5.3 report a descriptive analysis of the results obtained in terms of RTs and accuracy, with mean RTs and accuracy being reported for the different independent-variable intervals. Interval boundaries were established using quartile values.

RT Analysis

The final model adopted for RTs fitted the observed data with the r-squared of .52 and residuals were not correlated with the fitted values (r=.04). Random intercepts of items (s.d.=.07) and participants (s.d.=.14) were included in the final random effect structure, i.e., no random slope significantly increased the goodness-of-fit of the model. Table 5.4 reports the estimated fixed parameters of the final model, along with the significance tests. These parameters are expressed in log(RT) as the model was fitted using logarithmically transformed RTs.

Effects	**Estimate parameters log(RT)**	**MCMC mean value**	**pMCMC**	**Estimate parameters RT**
Intercept	6.5276	6.5276	.0001	704
Length	0.0425	0.0425	.0001	31
Compound frequency	-0.0596	-0.0596	.0001	-41
Comp. Semantic Transparency (ST)	-0.0878	-0.0875	.1290	-79
Headedness (H)	0.0244	0.0244	.1074	18
1st constituent frequency (freq1)	0.0017	0.0016	.8794	4
2st constituent frequency (freq2)	-0.0136	-0.0135	.1414	-10
ST * H	-0.1738	-0.1733	.0052	-125
freq1 * H	0.0101	0.0101	.2562	6
freq2 * H	-0.0255	-0.0255	.0004	-17
freq1 * ST	-0.0744	-0.0741	.0180	-59
freq2 * ST	0.0610	0.0607	.0192	41
freq1 * freq2	-0.0167	-0.0167	.0078	-11
freq1 * ST * H	-0.0811	-0.0808	.0128	-64
freq2 * ST * H	-0.0956	-0.0954	.0002	-71

Table 5.4: Fixed effects in the RT model; the final column reports the parameters that were estimated in the model after having been applied to the untransformed RTs

The effects of compound frequency and length emerged as significant: the more frequent a compound occurs, the faster it is recognized; on the contrary, the longer a compound is, the longer it takes to be recognized. The interactions of these variables with other predictors (constituent frequencies and semantic transparency measures) were not significant, i.e., their effect is independent of the other properties of the stimuli.

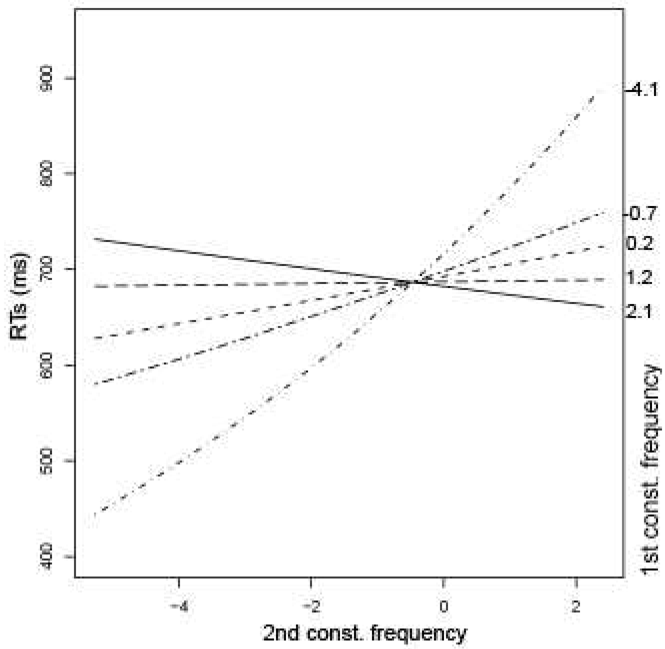

Figure 5.1: RT analysis; partialised effects of second constituent frequency, modulated by first constituent frequency.

However, interactions involving the frequency of the two constituents did emerge. As can be seen in figure 5.1, results indicate an interaction between first- and second-constituent frequency: the inhibitory effect of the second-constituent frequency on compound recognition is stronger when the first constituent is more frequent.

Interactions also emerged between constituent frequencies, compound semantic transparency and headedness. In head-initial compounds, the first constituent (Figure 5.2a) had a progressive inhibitory effect, which increased with the degree of transparency of the compound (although the effect was rather small); on the contrary, when the first constituent was the modifier, its frequency was more facilitating when the compound was more transparent

(Figure 5.2b). The second constituent showed an opposite effect pattern: higher degrees of semantic transparency are related to progressively more facilitating effects of constituent frequency in head-final compounds (Figure 5.2d), while more inhibitory frequency effects are associated to higher degrees of compound transparency in head-initial compounds (Figure 5.2c).

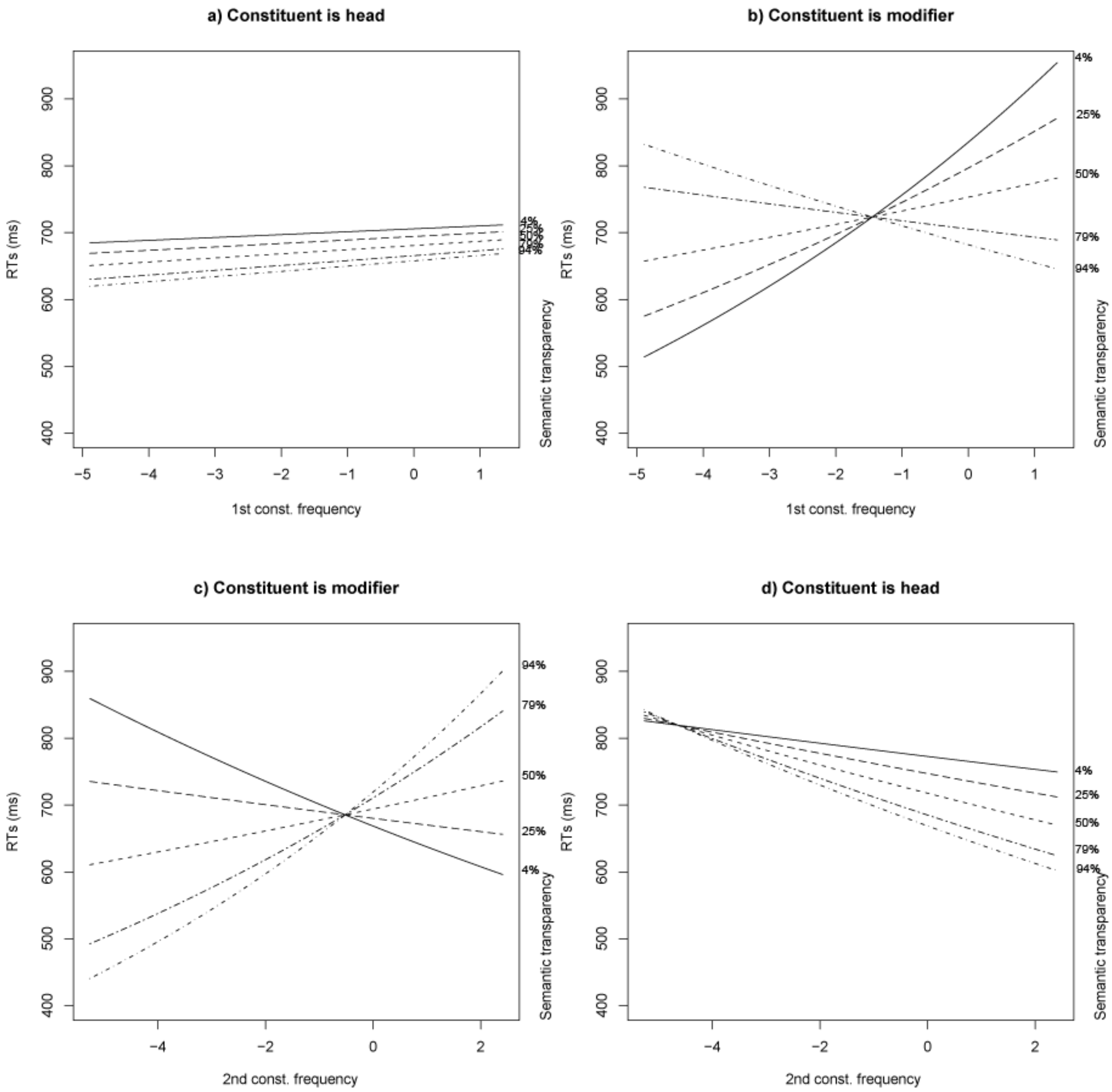

Figure 5.2: RT analysis. Upper panels: partialised effects of the first constituent frequency, modulated by semantic transparency, for head-initial (a) and head-final (b) compounds. Lower panels: partialised effects of the second constituent frequency, modulated by semantic transparency for head-initial (c) and head-final (d) compounds. The percentage of semantic transparency of the compounds is reported on different lines; higher values indicate a higher degree of transparency.

Accuracy analysis

When investigating the participants' accuracy, the final model fitted the observed data with the pseudo r-squared of .57, and the correlation between residuals and fitted values was .14. Random intercepts of items (s.d.=3.05) and participants (s.d.=2.07) were included in the final random effect structure. In the final model only fixed effects of first constituent frequency (Estimate=-1.09; z=2.04; p=.0415) and compound semantic transparency (Estimate=9.56; z=2.78; p=.0055) emerged. It could be argued that as the participants' performance was almost at ceiling (94%), the accuracy analysis was not sufficiently powerful for other effects and the interactions to emerge as significant (as observed in the model on RTs).

Discussion

The analysis of RTs in lexical decision revealed significance levels for several effects and a number of interactions involving morpho-lexical and semantic properties of both the compound and the constituents. These are examined individually in the following section.

Main effects

The significant effect of compound length was inhibitory, reflecting the reading time: longer strings take more time to read and thus to be identified as words. Most importantly, contrary to the results emerging from eye-tracking studies (Bertram & Hyönä, 2003), this variable does not modulate the access to constituent representations (i.e., there is no interaction between length and constituent frequencies). The discrepancy vis-à-vis the results emerging from the present study may be explained by the differences in the materials employed; indeed, the compounds used in the Finnish study were either longer than 12 letters or shorter than 8, while the length of the compounds in the present study is *between* 8 and 13 letters.

A significant facilitatory effect of compound frequency emerged, in line with findings in a number of previous studies (e.g., Pollatsek et. al., 2000; Kuperman et. al., 2008; Kuperman et al., 2009; Gagné & Spalding, 2009). However, results from the priming literature (e.g., Libben et al., 2003) consistently indicate routine access to constituent representations at an early stage. While a traditional interpretation of the compound frequency effect would indicate a whole-word representation of compounds, Baayen, Wurm & Aycock (2007) saw whole-word frequency as reflecting a combinatorial knowledge about morphemes (i.e., their joint probability), rather than a diagnostic measure for whole-word lexical representation. In other words, this measure would carry an acquired lexical knowledge, which is necessary to disentangle constituents as genuine meaning-bearing units (e.g., *corn* in *cornbread*) from orthographical strings which happen to correspond to morphemes (e.g., *corn* in *corner*). This is of particular interest to this study, since the frequency of our compound stimuli is relatively low (as in the materials employed by Baayen et al., 2007) but, a strong compound-frequency effect emerged nevertheless. The effect may thus reflect the joint probability of the constituents rather than an access to the whole-word representation, complementing the effects of constituent frequencies emerging in a number of interactions.

Two-way interaction

A two-way interaction between first- and second-constituent frequency was found. This interaction indicates that the second constituent frequency has no effect for low-frequency first constituents, but the more frequent the first constituent, the more inhibitory the second becomes. Interactions between compound and constituent frequencies are predicted by processing models conceiving parallel and interacting routes of compound processing (Kuperman et al., 2008; Kuperman et al., 2009). The resulting interaction between constituent frequencies is thus in line with Kuperman et al.'s predictions, indicating that different variables modulate each other, and are exploited in order to maximize the efficiency of word recognition. The present interaction may however be a consequence of the adopted experimental paradigm: the participants were asked to make a word/non-word decision on compounds, with both constituents immediately available due to the central fixation point. Under these conditions, constituents are arguably processed in parallel and the participants' choice capitalizes on the properties of both. In fact, the present results indicate that this processing might even slow down the participants' performance: while the first-constituent frequency is partially facilitatory (left portion of Figure 5.1), RTs tend to increase when accessing compounds in which both constituents are highly frequent. This inhibition may be due to a processing competition between the free forms of the constituents (emphasized by their high frequency) and the compound word for which the lexical decision is required. If this interpretation is correct, the effect will be limited to lexical decision experiments.

Three-way interactions

The effect of the constituent frequencies interacted with the headedness and the semantic transparency of the compound: in head-initial compounds a higher compound transparency was associated to inhibitory effects of constituent frequencies (left-side panel of Figure 5.2), while in head-final compounds, the facilitatory characteristic of the constituent frequency effect increased with the degree of transparency of the compound (right-side panel of Figure 5.2). Interpretation of this complex interaction requires a comprehension of how semantic transparency and headedness modulate frequency effects.

It should be remembered that the *compound* semantic transparency was involved in the three-way interaction. Although constituent transparency measures were also introduced in the regression model, their effects had no significant impact on the overall goodness of fit. Both measures have been used in the psycholinguistic literature, but consistent effects were rarely observed. In our view, the two measures subtend rather different theoretical constructs. While constituent transparency ratings are a good measure of *semantic similarity* between the compound meaning and the meanings of its constituents, compound transparency ratings arguably indicate the degree of *semantic compositionality* of the compound concept. In other words, constituent transparency measures the degree of semantic relatedness between two different meanings (e.g., *fish* and *swordfish*, *sword* and *swordfish*), the kind of relations which is efficiently modelled by semantic networks; in models of this kind each node represents a specific concept, and related concepts are represented by linked nodes, with activation spreading between each other. Constituent transparency ratings estimate the strength of these links. However, other models have been proposed for the processing of compound semantics. The degree of semantic compositionality, as measured by *compound* semantic transparency (Ji et al., 2011), would indicate how well the combination of the constituents represents the compound meaning (e.g., the degree to which “a fish with something shaped like a sword” is considered a good circumlocution for a *swordfish*). The latent variable it measures is therefore that studied by models of conceptual combination (e.g., Gagné & Spalding, 2007). In conclusion, we propose that the frequency effects which emerged in our study are more affected by the degree of semantic compositionality of the compound rather than by the strength of semantic similarity between different concepts. Constituent frequency effects arguably assess the ease of access to constituent meaning (for a more extensive discussion of the semantic nature of frequency effects, see Baayen, Feldman & Schreuder, 2006). The interaction between constituent frequency and semantic transparency is thus expected to emerge, indicating that the more the constituent meanings are involved in processing, the easier it is to integrate them in order to obtain the meaning of the whole compound (Gagné & Spalding, 2009). This interpretation is in line with the hypothesis of the influence of constituent families as the result of semantic/conceptual rather than lexical effects (Schreuder & Baayen, 1995; del Prado Martin, Deutsch, Frost, Schreuder, De Jong & Baayen, 2005).

Although semantic transparency may indicate the ease of semantic compositionality, it is by no means exhaustive in terms of how the two constituents should be combined. In other words, the interpretation of Italian compounds is always intrinsically ambiguous due to the headedness issue: the reader who is faced with the problem of how to interpret *astronave*, starship - “the star of the ship” or “the ship of the star”, - has to call on additional stored knowledge, which is arguably based on previous experience on compound nouns. We suggest that the processing mechanisms maximize their efficiency by assuming the most frequent structure as default: following the idea proposed in Chapter 2, and in line with the quantitative description of the Italian lexicon, the head-final structure could be the natural choice to shape the compound concept. In other words, the central semantic core of a compound is expected to be stored in the second constituent, and the first constituent is considered by default as typically modifying the second one.

On the basis of the above considerations, the three way interactions between constituent frequencies, headedness and semantic transparency can be explained by the assumptions of (i) a processing route dedicated to the semantic combination of constituent meanings, and (ii) a default interpretation of compounds following a head-final structure. When reading a compound, an integration of the constituent meanings is always attempted. The more the semantic combination is in line with the constituent meaning (i.e., higher semantic transparency), the greater will be the involvement of the constituent meanings in the access to the compound concept. This integration will follow a head-final structure, in which the first meaning is assumed to modify the second meaning. In fact, when a compound has a head-final structure (right panels in Figure 5.2), both constituents have a facilitating effect on compound recognition, and the more semantically transparent the compound, the greater the effect. On the contrary, in head-initial compounds (left-side panels in Figure 5.2), the second (modifier) constituent has an inhibitory effect on compound processing, reflecting the idea that the search for the head in the final position was unfruitful: in transparent compounds, the second constituent is by default considered the head; when this is not the case, the attempt of semantic integration leads to a time consuming conflict, since the head/modifier roles must be reassigned to the constituents. Empirical support for an assignment procedure of the head-modifier roles has been recently found in English speakers. Gagné, Spalding, Figueredo & Mullaly (2009) showed that the congruency of constituent roles between primes and targets is crucial when testing effects associated to conceptual combination (i.e., the relational priming effect); therefore, for example, when *fur gloves* is the target word, *fur blanket* elicits a larger priming effect than *fur trader*, but *acrylic fur* is no more facilitating than *brown fur.*

Even if an inhibitory frequency effect may seem surprising, this phenomenon has already been described, especially in relation to other psycholinguistic measures. Kuperman & Van Dyke (2011) in particular suggest that this effect is likely to be found when testing highly proficient readers (as our participants). Taft (2004) also showed that a reverse base frequency effect may arise for derived words at the morpheme combination level. Moreover, our results are in line with those of Baayen (2010b), indicating that larger family sizes may hinder compound recognition when the assignment of the head/modifier roles is ambiguous (the degree of ambiguity was modelled as the amount of connections in a graph, with all the possible compound constituents as nodes). The effect reported by Ji et al. (2011) is also highly consistent with the present findings. In English transparent compounds, the frequency of the first constituent has a facilitatory effect on word recognition; however, this effect reverses (leading to longer RTs) in the case of opaque compounds; noteworthy, the phenomenon is particularly evident when the conceptual combination between constituents is forced by experimental manipulations.

The three-way interactions also indicate that head-constituents have smaller frequency effects than their modifier counterparts. Their effects also tend to be less inhibitory for compound recognition, which arguably depends from the morphosynctactic properties of the head constituents. In fact, as mentioned above, the head of a compound is also important because it percolates its lexical properties (e.g., grammatical class, gender) to the whole compound. The effect of these properties (which, in the case of gender, are orthographically marked in Italian) is independent of semantic considerations, since lexical properties are percolated to a compound irrespective of its semantic compositionality. This information is an important cue for the identification of the head constituents: it provides an additional boost to compound access, and at the same time modulates the importance of semantic compositionality information in accessing the constituent role. Alternatively, the modifier may be associated to larger frequency effects in so far as it carries the relational information linking constituent meanings (Gagné & Shoben, 1997). Consequently, modifiers may be more sensitive to semantic modulation since they typically drive the conceptual combination processing.

Chapter 6:

The time course of constituent combination when reading compound words: an eye-tracking study.

In the previous chapter the processing of constituents appeared to be highly influenced by properties of the whole compound, i.e, semantic transparency and headedness. However, at least some of the observed results may depend on the experimental procedure used in the experiment, as strategic effects are likely to emerge in a lexical decision task, in which an explicit, non-verbal decision component is superimposed over the normal word recognition process. In particular, the interactions may be due to a potential strategic behavior, since they could reflect tradeoffs between different sources of information in a decision task. Moreover, the task described in Chapter 5 is blind to the time-course of lexical processing, reflecting only its final recognition stages. These issues were addressed in detail in the present study.

The aim of this experiment was twofold: to investigate whether the effects observed on RTs would extend beyond the lexical decision paradigm, as it is possible that a somewhat artificial condition as is the lexical decision task could elicit strategic behaviour which would not be observed in more ecological conditions, and to assess the time course of the observed effects, especially vis-à-vis the role of semantic transparency and headedness. This experiment therefore investigated the processing of nominal compounds in a reading task, and adopted fixation duration measures as dependent variables.

Materials and Methods

Participants

Forty neurologically intact, right-handed subjects participated in the experiment (mean age = 21±2, mean education = 16±2). All were native Italian speakers with normal or corrected-to-normal vision and no developmental reading disorders; they were attending the University of Milano-Bicocca as either undergraduates or postgraduates, and participated in the study in exchange for credits or as volunteers.

Apparatus

An EyeLink 1000 eye-tracker manufactured by SR Research Ltd. (Canada) was used to monitor the participants' eye-movements while reading; a chin-rest support was used to maintain the position of the head constant while a desktop camera sampled the pupil position and size at a frequency of 500 Hz. The recording was monocular.

Materials

The 48 compound words described in the previous Chapter were embedded in meaningful sentence contexts, as close as possible to the sentence centre. The context preceding them was always relatively neutral (i.e., it was not possible to anticipate the target compounds). The length of the sentences ranged from 66 to 98 characters (including blank spaces between words). The same psycholinguistic variables previously described were considered. Forty-two sentences without compound words were also introduced as filler stimuli.

Procedure

The eye-tracker was calibrated prior to the experiment by means of a three-point grid at the vertical centre of the screen. The stimuli, which were projected in black lowercase letters in random order on a white screen, were preceded by a fixation point in a central-left position. Each character subtended a visual angle of 0.63°, considering a mean viewing distance of 60 cm. Eye drift was checked by means of the fixation point before each individual stimulus was displayed.

Participants were asked to read and understand the displayed sentence and then press a button on the response pad. Each sentence remained on the screen until the button was pressed. About 20% of the trials were followed by a question on the general meaning of the sentence, requiring a yes/no response to be orally provided by the participants. A practice session, consisting of eight sentences, was run at the beginning of the experiment so that the participants could familiarize with the task,. The whole experimental session lasted between 15 and 20 minutes.

Data analyses

Only data concerning fixations on the target compounds were considered. Fixations that either preceded or followed a blink were excluded from the analyses. Datapoints that deviate from the normal distribution were also excluded, following the inspection of qq-plots. The procedure was validated by assessing kurtosis change after outlier removal (i.e., Anscombe-Glynn test was not significant anymore after the procedure; Anscombe & Glynn, 1983).

The analysis of the eye-movement data followed the same guidelines described for the lexical decision experiment. Three dependent variables were considered: duration of the *first fixation* on the compound, the sum of the durations of all first-pass fixations on the compound (*gaze* duration), and the sum of the duration of all fixations on the compound, including regressions (*total fixation duration*). The first fixation model was employed as a diagnostic tool for early lexical processing; for this reason, only compounds which were fixated more than once were considered in this analysis. The objective of this was to ensure that the dependent variable would only reflect the early processing of compounds; in fact, first fixation duration would also reflect later processing stages for compounds fixated only once. Gaze duration, on the other hand, indicated the time required for the entire word-comprehension process. The model on total fixation duration was used to investigate processing difficulties associated with the integration of the word meaning into the sentence frame (see Juhasz, 2007). The same effects and interactions described in Chapter 5 were analysed, with the exception of the fixation position, which was included in the first-fixation analysis as an additional predictor.

Results

Tables 6.1, 6.2 and 6.3 report a descriptive analysis of the results obtained in terms of first fixation duration, gaze duration, and total fixation duration, with mean values being reported for the various independent-variable intervals. Interval boundaries were established using quartile values.

Independent variable	**x < Q1**	**Q1 <x < Q2**	**Q2< x< Q3**	**x > Q3**
Compound Surface Frequency	235	269	233	230
1st constituent Surface Freq.	240	236	229	240
2st constituent Surface Freq.	243	230	240	234
Compound Semantic Transparency	238	245	231	234
1st constituent ST	240	235	238	233
2nd constituent ST	231	238	245	237
Length	239	240	235	226
Fixation Position	219	240	249	240

Table 6.1: Mean first-fixation durations (in ms) for different intervals of the independent variables (Q1 = first quartile, Q2 = second quartile, Q3 = third quartile).

Independent variable	**x < Q1**	**Q1 <x < Q2**	**Q2< x< Q3**	**x > Q3**
Compound Surface Frequency	400	439	381	350
1st constituent Surface Freq.	395	370	390	392
2st constituent Surface Freq.	421	374	370	375
Compound Semantic Transparency	430	407	333	370
1st constituent ST	392	375	418	364
2nd constituent ST	389	425	389	354
Length	353	388	397	450

Table 6.2: Mean gaze durations (in ms) for different intervals of the independent variables (Q1 = first quartile, Q2 = second quartile, Q3 = third quartile).

Target compounds were fixated only once in 50% of the experimental trials, while in the other 50% the number of fixations were as follows: twice (32%), three times (12%), four times (4%) and more than four times (2%). The mean duration of the first fixation was significantly longer for compounds fixated only once compared to stimuli receiving multiple fixation (MCMC mean = 11.43; pMCMC= .0010), confirming previously reported results (e.g., Vitu & O'Regan, 1995; Rayner, Sereno, & Raney, 1996). Go-back fixations on the target compound were observed in 42% of the sentences.

Independent variable	x < Q1	Q1 <x < Q2	Q2< x< Q3	x > Q3
Compound Surface Frequency	576	665	519	485
1st constituent Surface Freq.	546	499	563	567
2st constituent Surface Freq.	575	529	524	523
Compound Semantic Transparency	596	560	483	503
1st constituent ST	551	548	540	504
2nd constituent ST	553	615	513	518
Length	497	528	586	596

Table 6.3: Mean total fixation durations (in ms) for different intervals of the independent variables (Q1 = first quartile, Q2 = second quartile, Q3 = third quartile).

First Fixation Duration

The final model fitted the observed data with the r-squared of .29, and residuals were not correlated with the fitted values (r=.10). Random intercepts of items (s.d.=.03) and participants (s.d.=.12) were included in the final random effect structure, i.e., no random slope significantly increased the model goodness-of-fit. All target stimuli were fixated more than once by at least 24% of the participants, i.e., the whole set of target compounds was included in the mixed-effects analysis on first fixation durations. Table 6.4 reports the estimated fixed parameters of the final model, with the significance tests. These parameters are expressed in logarithmically transformed fixation durations.

Effects	Estimate parameters	MCMC mean value	pMCMC	Estimate parameters (ms)
Intercept	5.4484	5.4489	.0001	238
Compound frequency (CompFreq)	0.0001	0.0003	.9774	1.81
1st constituent frequency (freq1)	-0.0039	-0.0039	.6130	-0.37
Comp. Semantic Transparency (ST)	-0.0111	-0.0106	.7902	-2.97
Fixation Position (parameter 1)	-0.0017	-0.0017	.0234	-0.33
Fixation Position (parameter 2)	-0.0001	-0.0001	.0001	-0.01
freq1 * CompFreq	0.0155	0.0153	.0294	4.13
freq1 * ST	-0.0783	-0.0772	.0114	-18.23

Table 6.4: Fixed effects in the analysis on first fixation durations; the final column reports the parameters that were estimated in the model after having been applied to the untransformed fixation durations

A significant non-linear (inverse-U shaped) effect of fixation position was found. The effect was modelled employing a polynomial function requiring two parameters, and indicates that the closer the fixations are to the word-centre, the longer they become. The effect of compound frequency is modulated by the frequency of the first constituent (Figure 6.1a): the lower the constituent frequency, the more facilitatory is the compound frequency effect (i.e., it is associated with shorter fixation durations). An interaction between first constituent frequency and compound semantic transparency also emerged (Figure 6.1b): the greater the degree of transparency of the compound, the more facilitatory the frequency effect.

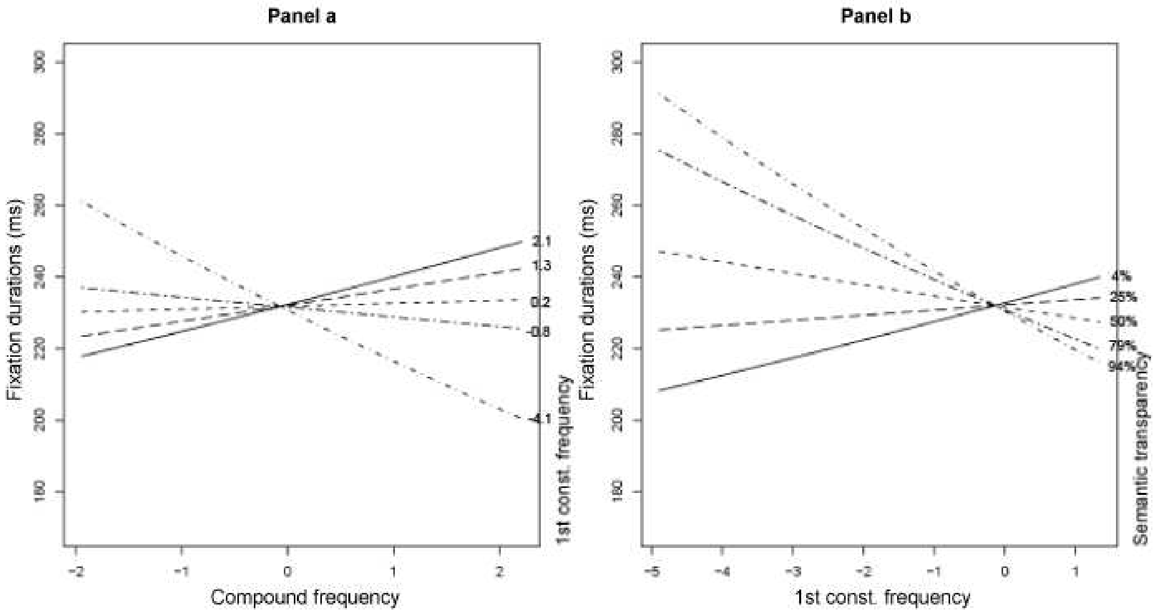

Figure 6.1: analysis on first fixation durations; partialised effects of compound frequency, modulated by first constituent frequency (a) and first constituent frequency, modulated by compound semantic transparency (b).

Gaze Duration

The final model on gaze duration fitted the observed data with the r-squared of .43, and residuals were not correlated with the fitted values (r=.06). Random intercepts of items (s.d.=.11) and participants (s.d.=.0001) were included in the final random effect structure. No random slope significantly increased the goodness-of-fit of the model. Table 6.5 reports the estimated fixed parameters of the final model, with the significance tests. The parameters are expressed in logarithmically transformed gaze durations.

Effects	**Estimate parameters**	**MCMC mean value**	**pMCMC**	**Estimate parameters (ms)**
Intercept	5.7749	5.7749	.0001	349
Length	0.0357	0.0358	.0204	15
Compound frequency	-0.0537	-0.0537	.0112	-19
Comp. Semantic Transparency (ST)	0.1093	0.1077	.3552	45
Headedness (H)	-0.0257	-0.0259	.4150	-9
1st constituent frequency (freq1)	0.0019	0.0020	.9068	1
2st constituent frequency (freq2)	-0.0146	-0.0147	.2304	-7
ST * H	-0.l194	-0.l185	.3020	-43
freq2 * H	-0.0055	-0.0057	.6552	-2
freq1 * ST	-0.1007	-0.1008	.0402	-39
freq2 * ST	0.1158	0.1150	.0080	45
freq2 * ST * H	-0.1212	-0.1215	.0082	-49

Table 6.5: Fixed effects in the analysis on gaze durations; the final column reports the parameters that were estimated in the model after having been applied to the untransformed gaze durations.

Effects of compound frequency and length are consistent with the results observed in the lexical decision task: higher compound frequencies are related to shorter gaze duration and longer compounds elicit longer gaze durations. An effect of first-constituent frequency was found, which was modulated by semantic transparency (Figure 6.2). Higher frequency leads to shorter gaze durations when compounds have a higher degree of transparency, and to longer gaze durations when semantic transparency is lower. This interaction does not involve headedness, i.e., it makes no difference whether the first constituent is the head or the modifier of the compound.

However, when the second constituent was considered an interaction emerged between its frequency, semantic transparency and headedness. When this constituent is the modifier of the compound, the frequency effect is more inhibitory (i.e., longer gaze durations) for more transparent compounds, and becomes progressively facilitatory as the degree of semantic transparency decreases (figure 6.3a). When the second constituent is the head, its frequency effect is not modulated by semantic transparency and is noticeably smaller (figure 6.3b).

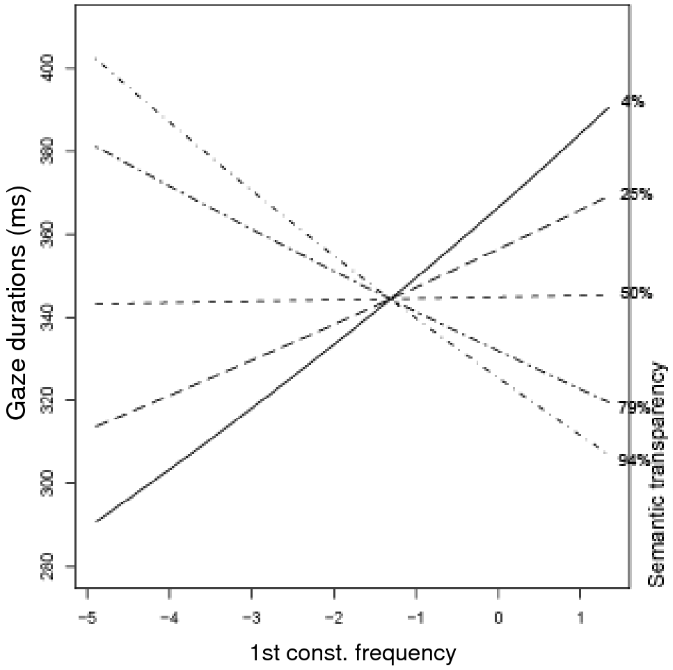

Figure 6.2: analysis on gaze durations; partialised effects of first constituent frequency, modulated by compound semantic transparency. The percentage of semantic transparency of the compounds is reported on different lines.

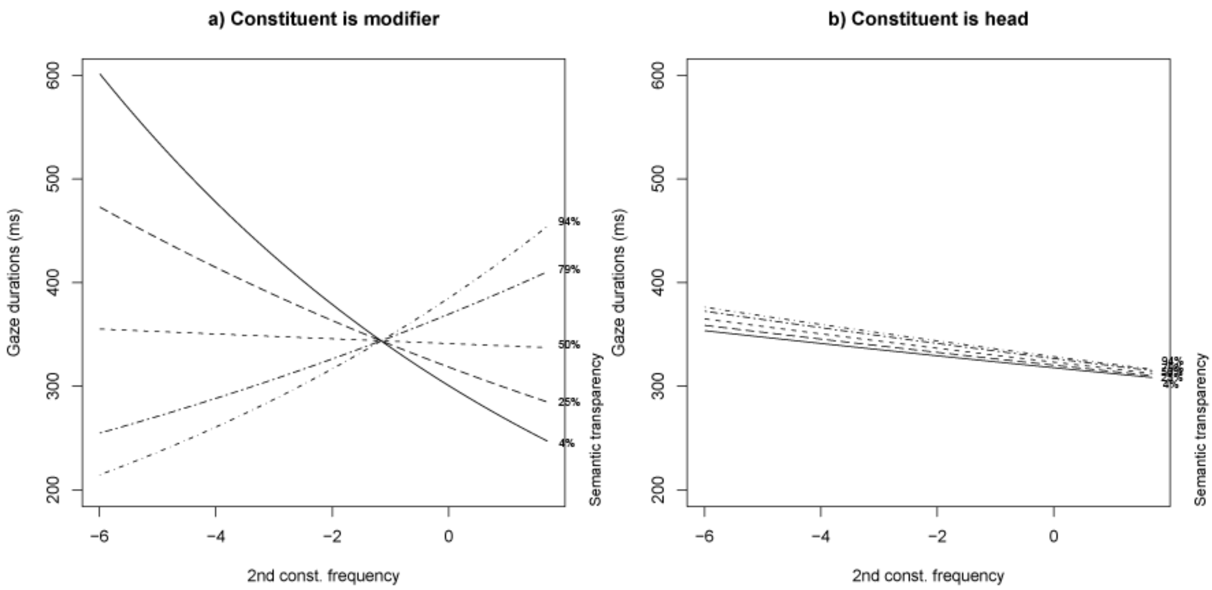

Figure 6.3: analysis on gaze durations; interactions between first constituent frequency and compound semantic transparency in head-initial (a) and head-final compounds (b). The percentage of semantic transparency of the compounds is reported on different lines; higher values indicate a higher degree of transparency.

Total fixation duration

The final model on total fixation duration fitted the observed data with the r-squared of .47, and residuals were not correlated with the fitted values (r=.05). Random intercepts of items (s.d.=.16) and participants (s.d.=.31) were included in the final random effect structure. No random slope significantly increased the goodness-of-fit of the model. Table 6.6 reports the estimated fixed parameters of the final model with the significance tests. The parameters are expressed in logarithmically transformed total fixation durations.

Effects	**Estimate parameters**	**MCMC mean value**	**pMCMC**	**Estimate parameters (ms)**
Intercept	6.0921	6.0911	.0001	501
Length	0.0480	0.0479	.0111	22
Compound frequency	-0.0759	-0.0757	.0024	-34
Comp. Semantic Transparency (ST)	0.1574	0.1576	.2511	29
Headedness (H)	-0.0192	-0.0196	.5874	-4
2st constituent frequency (freq2)	-0.0049	-0.0048	.7416	4
ST * H	-0.3697	-0.3691	.0078	-170
freq2 * H	-0.0234	-0.0234	.1238	-8
freq2 * ST	0.1364	0.1358	.0094	55
freq2 * ST * H	-0.1763	-0.1763	.0011	-85

Table 6.6: Fixed effects in the analysis on total fixation durations; the final column reports the parameters that were estimated in the model after having been applied to the untransformed total fixation times.

Effects of compound frequency and length are consistent with those found in the models on lexical-decision latencies (Chapter 5) and on gaze durations: higher compound frequencies were related to shorter total fixation times and longer compounds elicited longer total fixation times.

No significant two-way interaction was found. A three-way interaction emerged involving second-constituent frequency, semantic transparency and headedness. When the second constituent is the modifier of the compound, its frequency effect is associated to longer total fixation times for more transparent compounds, and becomes progressively more facilitatory as the degree of semantic transparency decreases (figure 6.4a). When the second constituent is the head, its frequency effect becomes progressively facilitatory as the degree of compound semantic transparency increases (figure 6.4b).

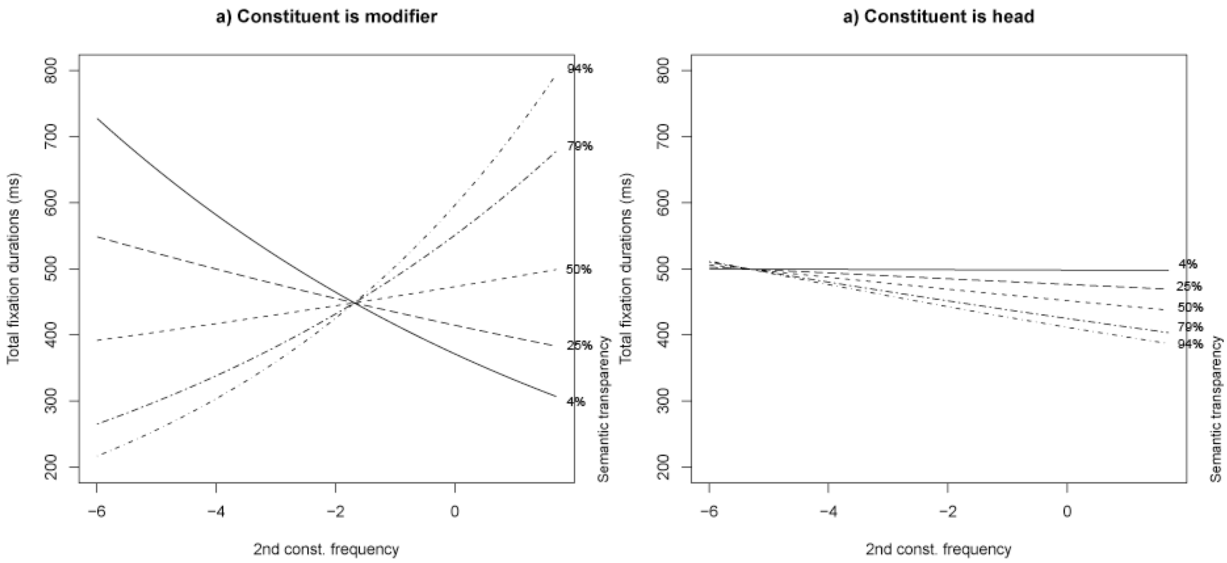

Figure 6.4: analysis on total fixation durations; interactions between first constituent frequency and compound semantic transparency in head-initial (a) and head-final compounds (b). The percentage of semantic transparency of the compounds is reported on different lines; higher values indicate a higher degree of transparency.

<u>Discussion</u>

First fixation duration: Main effect

Effects emerging in the analysis of *first fixation* durations are traditionally considered diagnostic of early stages of processing. A non-linear effect of the fixation position was found, indicating that fixations closer to the centre of the word result in longer durations. This is arguably due to the amount of information available in foveal vision: as more orthographic information is available when the word centre is fixated, more time is required to process it; when the fixation falls closer to the extremities of the word, less information is accessible and processing times are shorter (Vitu, Lancelin & Marrier d'Unienville, 2007).

First fixation duration: Two-way interactions

Our results indicate that there are a number of properties related either to the whole compound or to the first constituent which play a role from the earliest stages of word access. Of particular interest for the present experiment are the observed interactions between the frequency of the first constituent and both the compound frequency and the compound semantic transparency. The very presence of these interactions suggests that a) properties associated to the whole compound are accessed at the earliest levels of processing; b) these properties enter into a complex interplay with information related to the first constituent, which is a preferred entry key for compound access (as reported in literature; e.g., Taft & Forster, 1976); c) the semantic analysis is triggered in the initial stages of compound word processing. The interaction between the first constituent frequency and the compound frequency indicates that the latter facilitates the recognition of compounds with lower constituent frequency to a greater extent, and its effect decreases as the first constituent frequency increases. This effect confirms the results obtained in experiments in Dutch (Kuperman et al., 2009) and Finnish (Kuperman et al., 2008) and supports the hypothesis of a multi-route framework. This model conceives a flexible and co-operative lexical processing, which relies on both compound and constituent properties from the earliest stages of complex word identification. According to Baayen et al. (2007), compound frequency may be related to the joint probability of the constituents, and thus indicate a reader's experience in integrating them; in this interpretation, high-frequency compounds would benefit more from access to its constituents than low-frequency compounds (Kuperman et al., 2009).

Interaction between the first constituent frequency and the compound semantic transparency was also found. Consistently with the results obtained by Ji et al. (2011), the frequency of the first constituent is associated to shorter fixations for very transparent compounds, and its effect becomes more inhibitory in relation to the opacity of the compound. Considered together with the interaction with compound frequency, this effect indicates that properties regarding the whole compound are accessed as early as at the first fixation. Information about the compound's semantic compositionality is available from the start of lexical access, and the first constituent effect changes depending on it: when the compound meaning can be accessed combining the meanings of its constituents, the frequency of the first constituent would boost word recognition (because its meaning is more easily accessed); however, when the compound meaning is more opaque, the constituent enters into competition with it (e.g., Frisson, Niswander-Klement & Pollatsek, 2008), leading to longer fixation durations. The interaction includes the *compound* semantic transparency, while semantic transparency of the constituents is not significant. As compound transparency can be considered as a measure of semantic compositionality (Ji et al., 2011), this interaction should be interpreted in terms of a processing route dedicated to the semantic combination of constituent meanings. Moreover, in this analysis headedness does not play any significant role, indicating that information concerning the compound structure is not accessed until later processing stages. The interaction between first constituent frequency and compound semantic transparency would thus reflect the first stage of the conceptual combination procedure, in which only partial semantic information is available: the combination of the constituent meanings has begun (either successfully or unsuccessfully, depending on compound transparency), but a full processing of the second constituent is still required in order to access the compound structure.

Since the effects of compound frequency, as well as compound semantic transparency, are crucially related to the processing of both constituents, these interactions indicate that, to some extent, also the second constituent is accessed during first fixations. As proposed by Kuperman et al. (2008), this may be due to a guessing strategy concerning the compound identity, based on low-level information (e.g., first letters of the second constituent, length of the word) available parafoveally. A similar interpretation of the effect was recently suggested by Baayen, Milin, Filipovic-Durdevic, Hendrix & Marelli (2011). In this model orthographic information about the first constituent is associated to the second-constituent meaning because of a discriminative learning procedure. Under this interpretation, the second constituent would be partially active thanks to the processing of the first part of the compound, and this information would be enough for the conceptual combination procedure to begin.

Gaze duration: Main effects

Gaze duration is assumed to reflect the entire word processing, so we expected that the results of this analysis would be consistent with those of the lexical decision experiment and indeed main effects of length and compound frequency were found, confirming the results reported in Chapter 5: the longer the compound, the longer the gaze duration, while the more frequent the compound, the shorter the gaze duration.

Gaze duration: Two-way interaction

A slight discrepancy emerged between the results on lexical decision latencies and gaze durations. In the lexical decision experiment the first-constituent frequency effect was qualified by an interaction with both semantic transparency and headedness, while in the gaze duration analysis the first-constituent frequency interacts with semantic transparency only. This provides confirmation that compound semantic transparency modulates constituent frequency effects, but in a slightly different way from that observed in Chapter 5. The first-constituent frequency interacted with the semantic transparency of the compound: in more transparent compounds, the effect was facilitatory, while in more opaque compounds, the effect was inhibitory. There was no involvement of headedness in this interaction, which indicates a purely positional effect of the first constituent as suggested by Taft & Forster (1976) and by eye-tracking studies (e.g., Hyönä & Pollatsek, 1998) (although as these studies were conducted with English and Finnish participants respectively, it was not possible to disentangle effects of headedness and position). This effect is at odds with the interaction observed in the lexical decision experiment (first-constituent frequency by semantic transparency by headedness), which could be attributed to a task-specific effect. Since a central fixation point was employed, information about both constituents was immediately available, triggering parallel processing and permitting access to the head-modifier structure from the beginning. It should be kept in mind that a sentence reading task in which lexical information is obtained sequentially through a left-to-right reading procedure – i.e., more naturally - was used to analyse gaze duration. The early interpretation of this effect is confirmed by the consistent pattern of results observed in the first-fixation model: the interaction emerges very early, and may indicate the first step in a left-to-right incremental process aimed at integrating the meanings of the two constituents.

Gaze duration: Three-way interaction

The three-way interaction between the second-constituent frequency, headedness and semantic transparency is consistent with the results of the lexical decision experiment. In particular, the constituent-frequency effect is small and facilitatory in head-final compounds (i.e., when the constituent is the head) and is not modulated by semantic transparency. However, when the second constituent is the modifier, it inhibits transparent compounds, and facilitates opaque ones. This interaction is informative of later stages of processing, in particular concerning the semantic combination procedure. The modulation of headedness indicates that full access to the second constituent is necessary for the compound structure to play its role. In line with the hypothesis of the default head-final structure, head-final compounds are easier to process, with a facilitatory – albeit small - effect of the second-constituent frequency. On the contrary, in head-initial compounds attempts to combine constituents semantically lead to a conflict in the attribution of head-modifier roles which has to be solved: in fact, when the second constituent is the modifier of a transparent compound, the default structure has to be updated, which is associated with longer gaze duration. Moreover, at this later stage of processing, semantic combination would be attempted only when possible (i.e., in semantically transparent compounds), an option that has been evaluated at early stages (see discussion of the results on first fixation durations). Hence the facilitatory effect of the constituent frequency in opaque compounds could be related to a purely lexical recognition process, and not reflect a peculiarity of the semantic-combination route.

In line with the results on the lexical decision task, the frequency effects of the head-constituent are smaller than those of the modifier, and its interaction with semantic transparency is less marked. This confirms the hypothesis that morphosyntactic properties also play a role in the headedness effect, a role that is partially independent of the semantics of the compound, but that nevertheless facilitates compound access. This concurrent and co-operative exploitation of all possible cues in order to maximize word-recognition efficiency is in line with the prediction of the multi-route model proposed by Kuperman et al. (2009).

Gaze duration: Further considerations

The interaction between the constituent frequency measures which emerged in the first experiment was not found in the gaze-duration analysis. As in the two-way interaction between first constituent frequency and semantic transparency, this may be due to specific effects related to the lexical decision task (e.g., timing: participants were asked to be as rapid as possible; position: both constituents were immediately detectable due to the central position of the fixation point). It is conceivable that these conditions could have given rise to a form of competition between the lexical items which were simultaneously presented, while this is much less likely to occur in the sentence reading task, where processing is serial.

Total fixation duration: Main effects

The effects observed in total fixation duration are consistent with the analysis on gaze duration. Main effects of length and compound frequency were found; the longer the compound, the longer the total fixation time, and the more frequent the compound, the shorter the total fixation time. Indeed, the meaning of a frequent compound should be easier to access and, as a consequence, to integrate into the sentence. Conversely, the longer the compound, the greater the number of fixations it is likely to attract (and thus the total fixation duration would increase).

Total fixation duration: Three-way interactions

The interaction between second constituent frequency, headedness and compound semantic transparency is fully in line with the effects observed in lexical decision latencies and gaze durations (compare Figure 6.4 with Figure 6.3 and the lower panels of Figure 5.2). Since the *total fixation duration* is assumed to reflect the processing load required to semantically integrate a word in its sentence frame, the three-way interaction confirms that the second constituent is assumed to be the head when trying to build the compound meaning. In fact, when a conceptual combination between constituents is possible (i.e., high semantic transparency), it is much easier to integrate the compound meaning into the sentence if the second constituent is head rather than modifier, suggesting that combining constituents is easier for head-final than head-initial compounds.

Conclusions

In this experiment fixation times on compound words were analysed in a sentence reading task to test the role of headedness and the influence of modulating variables (semantic transparency in particular) on compound visual processing. The constituent-frequency effects were analysed to assess the access to constituent representations. The effects of the psycholinguistic variables were assessed employing mixed-effects regression analyses. Fixation times on compound words were analysed in a sentence reading task. The results indicated main effects of compound frequency and length and interactions between compound semantic transparency, headedness and constituent frequency measures.

The overall results of the present study indicate that information concerning both the compound and its constituents is accessed during compound processing; these cues dynamically interact during compound recognition and are influenced by the compound's semantic and lexical properties. These results only partially fit strictly parallel dual-route models: in the first place the two routes do not seem to run parallel, since the compound and constituent properties influence each other during compound access, and in the second place, the relative weight of the two routes seems to be modulated by semantic transparency (see the third-level interactions) rather than by whole-word frequency (e.g., Schreuder & Baayen, 1995) or length (Bertram & Hyönä, 2003). Moreover, semantic transparency effects emerged at very early processing stages (see the results of the analysis on first-fixation duration), indicating that even models conceiving semantic effects at late stages only (Libben, 1998; Juhasz, 2007) do not fit the present results.

The multi-route model (an evolution of the dual-route model by Schreuder & Baayen, 1995), which assumes an early simultaneous access to multiple sources of information (Kuperman et al., 2008; Kuperman et al., 2009), is probably best suited to explain our data. Several predictions of this model are confirmed in the present study: indeed, interactions between various lexical and semantic measures were found both in early and late processing stages. However, this model does not explicitly implement the morphosyntactic information that is associated with the head-modifier structure, nor the idea of a conceptual combination procedure. Our results indicate that the model should be complemented with a semantic route, dedicated to the conceptual combination of constituent meanings (e.g., Gagné & Spalding, 2007; Gagné & Spalding, 2009). We propose that this meaning-composition process, instead of operating on the information activated by the ongoing lexical retrieval, should be conceived as a separate route that operates in parallel (and constantly interacts) with the lexical processing of a compound and of its constituents. This semantic route would be triggered from the very beginning of word processing, and the conceptual combination would start from the first constituent (hence its early interaction with semantic transparency), in a left-to-right incremental procedure. Information about the compound head-modifier structure (i.e., regarding how constituents should be combined) is only accessed at a later stage, and mainly in the case of highly transparent compounds (viz., the three way interactions found in the analyses on gaze duration and total fixation duration). Our hypothesis is that in Italian this semantic route takes the head-final structure as the default architecture in order to combine constituents. When this assumption is not satisfied (i.e., as in head-initial compounds) head-modifier roles have to be reassigned in a time-consuming process (consistently with Gagné et al., 2009).

To summarize, the main finding of the present study is the influence of headedness and semantic transparency in compound processing. The effect of semantic transparency on compound recognition has long been debated in psycholinguistics, and many experiments have failed to replicate it (e.g., Zwitserlood, 1994; Pollatsek & Hyönä, 2005). This study shows that a semantic route is indeed involved in compound processing, even if its contribution is weak compared to those of other lexical cues; in fact, its effect can be rather faint and is always qualified by interactions with constituent frequencies. It is therefore possible that semantic transparency effects were not reported in many experiments due either to low-power factorial designs, or the absence of a test of the critical interactions. A partial confirmation of this hypothesis is provided by the study by Pollatsek & Hyönä (2005), who found an interaction between semantic transparency and the first-constituent family size in a regression analysis only, and by Ji et al. (2011), who found modulation of semantic transparency only when the experimental manipulations enhanced the (de)composition procedure. It should also be kept in mind that the absence of semantic effects in many priming experiments may be a task-related phenomenon: recent results suggest that priming effects mainly depend on the type of task adopted (Norris & Kinoshita, 2008), and that a lexical decision task may suppress semantic effects (Bueno & Frenck-Mestre, 2008).

Headedness effects have rarely been described. My hypothesis is that Italian speakers assume a head-final structure as default when processing compounds, which may be somewhat unexpected as traditionally head-initial compounds have been said to be predominant in Romance languages, a theory which however has been recently challenged (Schwarze, 2005), as illustrated in Chapter 2. The superiority of head-final compounds could thus be represented at mental level for reasons related to the distributional properties of Italian lexical morphology: the majority of complex Italian words take the lexical–semantic properties of the rightmost morpheme, and head-initial compounds represent an exception, in which the central properties of the whole word have to be extracted from the initial morpheme.

In conclusion, the results of the present study indicate that semantic modulation plays an important role in Italian compound processing, influencing lexical access at different levels. Assessing compound-noun processing in a Romance language permitted also evaluation of the mental representation of headedness, which is impossible to test in the Germanic languages and in Finnish. This led to unexpected results; indeed, the headedness effect is position-specific, mainly emerging for the rightmost constituent.

General Discussion

In this dissertation I investigated the processing of Italian compound nouns throughout a series of psycholinguistics and cognitive neuropsychological experiments. Aim of the of this thesis was to propose a unified explanation for the whole-word and structure effects observed in compound processing. To summarize, the results indicate that the variables related to the whole compound (i.e., compound headedness, whole-word frequency and semantic transparency) play a crucial role in word processing, and that the lexical and grammatical properties of constituents are also accessed.

In particular, in Chapter 1, I reported a whole-word effect and an effect of compound headedness in reading, and showed how they both could be parsimoniously explained by hypothesizing a unique compound lemma representation. In Chapter 2 and 3, converging evidence was found for a rule indicating the head-final structure as the default one when processing compounds. This rule would operate at central processing levels (either semantic or lemmatic), and would be related to the appreciation of the distributional properties of Italian morphology. In Chapter 4, I reported a number of findings in favor of a multiple lemma representation of compound words, indicating that not only the compound lemma is active during processing, but also the grammatical representations of constituents. Finally, in Chapter 5 and 6 I found evidence confirming that the head-final assumption emerges at central processing levels, and suggesting that it is better interpreted as a principle guiding the conceptual combination of constituent meanings. This procedure would work in parallel with lexical access, in an architecture conceiving multiple interacting processing routes.

The theoretical frameworks adopted in the chapters were indeed quite variegated. While Chapters 2 and 3 were mainly aimed at understanding the head-final rule, and its potential role in word processing, the remaining studies were heavily based on the predictions of two theoretical models proposed in the psycholinguistic literature. Namely, Chapter 1 and 4 mainly referred to the stage model proposed by Levelt et al. (1999) and the distinction between lemma and lexeme levels; conversely, the results of Chapter 5 and 6 were interpreted within the multiple route model proposed by Kuperman et al. (2008), and the conceptual combination procedure mainly studied by Gagné & Spalding (2007). These architectures are indeed quite different, but they are both based on the same theoretical hypothesis: the principle of maximization of opportunity (Libben et al., 2007). Both the multiple and interactive routes proposed by Kuperman et al. (2008) and our (massively interactive and redundant) reinterpretation of the lemma-lexeme levels are systems which maximize the chances of an efficient word processing. Therefore, I will hereby propose a hybrid model, comprising both multiple processing stages and parallel processing routes.

A simplified representation of the architecture we propose is shown in Figure GC1. The leftmost part of the figure is organized following the idea of the lemma-lexeme distinction. The lexeme levels are two storage systems containing either the orthographic or phonological representations of morphemes. These modules are completely blind to grammatical or semantic information; in other words, at peripheral levels, morphemes are simply conceived as orthographic or phonological clusters frequently occurring in the lexicon. In fact, lexeme representations seem to be organized following a full (de)composition model (Taft & Forster, 1975), as suggested by the qualitative errors reported in the neuropsychological studies (Chapters 1 and 4) and the effects of constituent priming and constituent frequency (Chapters 2, 5 and 6). The lemma level stores the grammatical properties of word and morphemes. At this level whole word effects (as reported in Chapter 1 and 4) are likely to emerge, due to the activation of compound lemma nodes. However, also the constituent lemma nodes seem to be activated, in a redundant and flexible multiple lemma representation. The compound lemma node would also represent the stored knowledge about the head-modifier structure, specifying whether the read compound is either head-initial or head-final, and how the constituent representations should be combined in order to access the compound meaning.

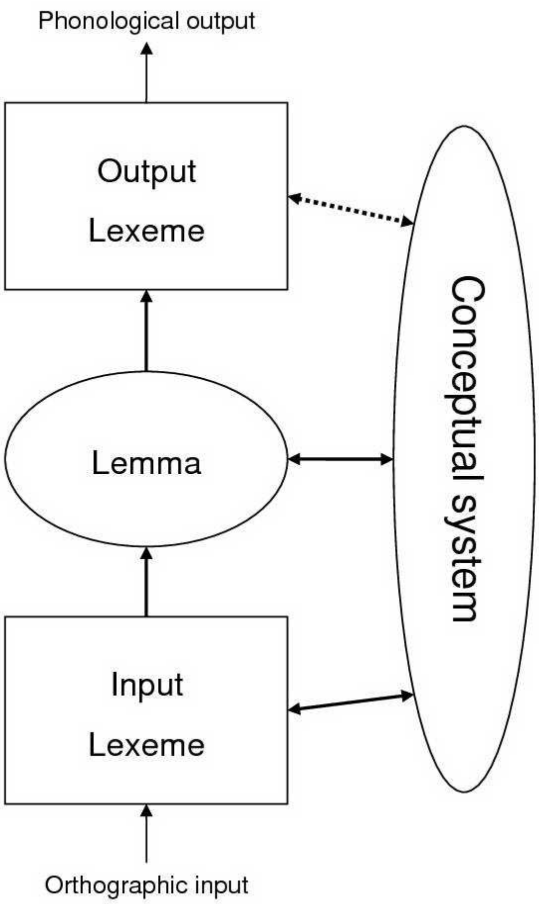

Figure GC1: scheme of the hybrid model of word reading

I also hypothesized a conceptual system working on the activation spreading from the input lexeme and operating in parallel throughout the whole lexical process. In fact, this parallel semantic procedure is continuously interacting with the lexical route, with information flowing in both directions (as in the architecture proposed by Kuperman et al., 2008). The conceptual system is based on combinatorial procedures, which merge constituent semantic information in order to obtain the compound meaning. The assumption of right-headedness (Chapters 2, 3 and 5) is likely to be found within this procedure. In fact, unaware of the actual compound structure, the conceptual combination procedure would follow the most likely structure, that is, the head-final one. In the case of head-initial compounds, the real compound meaning can be obtained only when the stored syntactic information spreads from the lemma to the conceptual system. This architecture would also explain the eye-tracking results (Chapter 6), since the lexeme level would activate the constituent meaning through a left-to-right processing, accounting for the interactions involving the first-constituent that emerged in the first fixation models. Other effects, involving compound headedness and the second constituent, emerge only later (on gaze durations and total fixation durations), and have in fact their source at the interplay between the conceptual and the lemma system.

Obviously, the model still needs to be tested and to be completed. For example, I have not yet studied the flow of information from the conceptual system to the output lexeme (but there are evidence in favor of it, see Barbieri, Basso, Frustaci & Luzzatti, 2010). Similarly, the interplay between the lemma and the conceptual system is far from being fully specified. However, the hybrid architecture I propose is indeed promising, and I think that even the present, incomplete, formulation is able to parsimoniously explain the many effects reported in the experimental part of this dissertation.

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