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Reading compounds in neglect dyslexia: The headedness effect

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ABSTRACT

Reading compound words was studied in neglect dyslexia in order to assess the influence of 'headedness'. The 'head' of a compound is the component that determines the grammatical category, the syntactic (e.g., the gender) and the semantic properties of the compound as a whole. For example, in the word 'blackberry' *berry* is the compound's head. The question was addressed of whether or not the privileged status of the head constituent influences processing and determines behavioural patterns in the breakdown of spatial attention in neglect. Italian right-headed (e.g. *capobanda*, band leader) and left-headed compounds (e.g. *astronave*, spaceship) were administered to 18 participants affected by neglect dyslexia. Left-headed compounds were read better than right-headed compounds. This result was not due to factors such as frequency, familiarity, age of acquisition or imageability, since these effects were controlled. It is suggested that attention is captured by the head component after implicit reading of the whole word. The head would require a relatively lighter processing load than the modifier and benefit from top-down facilitation.

1. Introduction

Neglect dyslexia, a condition that may accompany but also be dissociated from other manifestations of visuo-spatial neglect (Bisiach, Meregalli, & Berti, 1990; Bisiach, Vallar, Perani, Papagno, & Berti, 1986; Vallar, Burani, & Arduino, 2010), manifests itself through the misreading of letters, words or strings of words that occupy the controlesional side of visual space. Neglect errors produced in single word reading, due to right-sided lesions in the most common variety, can thus be omissions and substitutions of, or (less frequently) additions to, the leftmost portion of the word. However, neglect does not appear to uniformly affect all types of material. Importantly, the literature reveals that reading errors may be influenced by the lexical status of the target, especially when the deficit is not severe (Arduino, Burani, & Vallar, 2002; Behrmann, Moscovitch, Black, & Moser, 1990; Cubelli & Beschin, 2005). In fact, a proportion of neglect patients may read words better than nonwords (Behrmann et al., 1990; Brunn & Farah, 1991; Sieroff, Pollatsek, & Posner, 1988). Reading nonwords consisting of a real root and a real affix may be easier than when they contain neither (Arduino et al., 2002). Moreover, words with more orthographic neighbours are more difficult to read than words with few orthographic neighbours (Arguin & Bub, 1997; Riddoch, Humphreys, Cleton, & Fery, 1990). Stored lexical knowledge thus seems to interfere with defective visuo-spatial processing and to compensate, at least partially, for the attentional problem. This is interpreted (Arduino et al., 2002) as supporting 'late selection' views of attentional processing (Deutsch & Deutsch, 1963; Umiltà, 2001; more complex, interactive views, are also compatible with this interpretation, e.g., Behrmann, Moscovitch, & Moser, 1991). It suggests that spatial attentional components, the impairment of which leads to neglect dyslexia, may also operate at a later stage of processing, after the information presented in the unattended visual area has undergone a higher-level analyses, including lexical and semantic processing.

One common finding (e.g. Behrmann et al., 1990), is that when reading compound words, patients affected by neglect dyslexia seem, in the case of two-word compounds, to respect the boundaries between the first and the second component. Thus, in left-sided neglect, they would omit or substitute the first component more often than the second component; the integrity of the second component is mostly respected.

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The present study exploits this finding in order to assess the influence of 'headedness'. A compound's 'head' is the component that determines the grammatical category, the syntactic (e.g., the gender) and the semantic properties of the compound as a whole. Thus, for example, in the word *blackberry*, *berry* is the compound's head. It determines the grammatical category and the syntactic properties of the compound: the word *blackberry* is thus a noun because the head component *berry* is a noun, while the other component (the so-called 'modifier') *black* is an adjective. Likewise, the Italian word *astronave* (spaceship) is feminine, because the head *nave* (head) is feminine, while the modifier *astro* (star) is masculine.

The question arises of whether or not the privileged status of the head constituent influences processing and determines behavioural patterns in the breakdown of spatial attention present in neglect. A major problem underlying efforts to understand the role of headedness in the processing of compounds is the possible confound constituted by the component's position. In languages such as English or German, the head is always in second position. Thus positional and headedness effects cannot be teased apart easily. As a consequence, neuropsychological studies of compounds are now relatively numerous (for reviews see Semenza & Mondini, 2006, 2010) although in contrast, investigations on headedness are remarkably few. One possible strategy for solving this problem may be to study bilingual patients. Jarema et al. (2007, 2010) contrasted French and English compounds that differed in the position of the head (left-sided in French, e.g., 'certificate medicale', and right-sided in English, e.g., 'medical certificate') in three bilingual patients. Their results revealed that headedness and position interact in the processing of compounds and that aphasic patients are sensitive to compound-internal structure: the head component tends to be preserved with respect to the modifier. A language that allows a direct comparison is Italian. In Italian, since noun–noun compounds can be either right-headed or left-headed, the spatial position of the head within the compound can be easily manipulated. Thus, how the electrophysiological correlates of processing compound words vary according to the position of the head could be shown in Italian speaking subjects (El Yagoubi et al., 2008).

Italian is also the language chosen for the present study. The interest of this study is twofold. In the first place, it aims to provide information about the extent to which lexical factors can influence selective attention. In turn, it explores the function of headedness, a concept formulated in theoretical linguistics. If an effect related to headedness were in fact found, the role and the relative importance in processing of the head constituent with respect to the modifier would be further highlighted.

2. Methods

2.1. Participants

Italian-speaking participants ($n = 18$: 12 males and 6 females), suffering from vascular injuries confined to the right hemisphere and affected by left-sided neglect, took part in this study. They were all-right handed and free from linguistic disorders. Their mean age was 66.27 years old, ranging from 50 to 89 years. Their mean education level was 8.72 years, ranging from 5 to 13. Neglect was diagnosed via administration of the Bells test, BIT (behavioural inattention test) conventional (score range: 29–118/146) and BIT behavioural (score range: 9–57/81) tests. On the basis of clinical findings and formal tests (line bisection and copy of drawings), neglect of participants was classified as the egocentric type in all cases. Table 1 reports demographical data, evaluation of neglect and the site of the lesion for each participant, as evidenced by either CT scan or MRI. The bulk of the lesion was identified by a neuroradiologist blind to the participants' symptomatology and the purpose of this study.

2.2. Materials

The experimental items consisted of 88 Italian compound words: 28 transparent left-headed noun–noun compounds (e.g. *capobanda*, band leader), 28 transparent right-headed noun–noun compounds (e.g. *astronave*, spaceship). 32 exocentric verb–noun compounds (e.g. *cavatappi*, corkscrew) were used as fillers. Left-headed and right-headed compounds were taken from El Yagoubi et al. (2008). Headedness was established according to a semantic criterion: the constituent that is the semantic referent of the whole compound was considered as head (e.g. *astronave,* spaceship, lit. 'star-ship', indicates a type of *nave*, ship. Thus, *nave,* ship is head of the compound). In the great majority of the cases, headedness established with this criterion leads to the same classification of other possible criteria (e.g., a syntactic criterion). The only items in the whole list whereby the semantic and the syntactic criteria disagree were *boccaporto* (hatchway, left-headed) and *crocevia* (crossroads, right-headed). With very few exceptions (e.g., *toporagno*, schrew), all items were semantically transparent.

The following lexical properties of the entire compounds and constituents were considered: familiarity, frequency, and age of acquisition, imageability, length, neighbourhood and family size. Length was calculated as number of letters. Frequency, neighbourhood and family size were calculated from a large corpus of written Italian (http://dev.sslmit.unibo.it/corpora). Age of acquisition, imageability and familiarity ratings were obtained from native Italian speakers on a seven-point Likert scale. Three different groups of 30 participants rated each one of the variables for compounds and three other groups rated the same variables for constituents.

Right-headed noun–noun compounds were found to be acquired later [$F(1, 54) = 6.13$; $p < 0.05$] and to be less imageable [$F(1, 54) = 6.45$; $p < 0.05$] than left-headed compounds. All other variables for whole compounds were statistically matched.

The first constituent of compounds was matched for all psycholinguistic variables, while the second constituents of left-headed compounds were more imageable [$F(1, 54) = 7.029$, $p < 0.05$] and acquired earlier [$F(1, 54) = 10.725$, $p < 0.05$] than the second constituents of right-headed compounds.

The possibility of guessing the first component when given the second component was also assessed in two different ways. First, the conditional probability of encountering, in Italian (as represented in the word corpus used), a specific compound (e.g., *astronave*) given the second constituent (*-nave*) was computed. According to the method described in Kuperman, Bertram, & Baayen (2008), this probability was computed as the ratio of two probabilities: the probability of encountering a given compound, estimated by the relative frequency of the compound, and the probability of encountering any compound ending with a given constituent. In the *-nave* example, this last probability is represented by the sum of all relative frequencies of all compounds ending with that constituent (e.g., *astronave*, *motonave*). These conditional probabilities were thus compared between the three categories. No difference was found between the categories [Kruskal–Wallis $\chi^2(2) = 3.46$; $p = 0.18$]. Because of the relevance for the study a comparison between right-headed and left-headed compounds was made and no significant difference was found [Wilcoxon $W = 342$; $p = 0.41$]. Secondly, control subjects ($n = 10$) were given the list of the second constituents and, knowing that these items were parts of compound words, they were asked to guess the first constituent. There was no difference in the number of correct guesses between the categories [Kruskal–Wallis $\chi^2(2) = 1.01$; $p = 0.6$], and no difference was found between left-headed and right-headed compounds [Wilcoxon $W = 325$; $p = 0.26$].

2.3. Data collection and analysis

Words were displayed on a 19-inch Acer computer screen. All stimuli appeared in black on a white background with a size 44 Arial typeface, in upper case. All of the words were presented in two conditions: centered in the middle of the screen according to the physical length, or according to the morphemic structure, i.e. with the boundary between the two constituents centered in the middle of the screen. Stimuli were presented to each participant in a random order. The participants were asked to read each word aloud. Once the word was read the examiner pressed a key to switch to the following word. Each participant was administered one or more (up to six) lists, in the effort to collect as much data as possible.

Only errors made exclusively on the left component of noun–noun compounds were considered for data analysis. This led to the exclusion of 43 errors, which either concerned the whole word (the large majority) or the rightmost component. No significant difference was found for the occurrence of these errors between right-headed and left-headed compounds. An exception was made for including two errors where the second component was embedded in another real word and the error consisted in reading just that word. For example, on one occasion the compound *fotoromanzo* (story told in pictures), composed of *foto* (picture) and *romanzo* (novel), was read as *manzo*, which is the Italian word for young ox. Thus, the final analysis concerned a total of 417 errors. Table 2 shows how many lists each of the participants read and the total number of errors they made.

The errors were classified as follows: omission errors, substitution errors (divided into visual-orthographic and lexical errors) and non-classifiable errors.

"Omission" errors consisted of omission of the leftmost constituent. Thus, in the example *audiofrequenza* (audio-frequency) the whole leftmost constituent was omitted, resulting in *frequenza*. In the examples *terremoto* (earthquake) or *affittacamere* (landlord), instead, only part of the leftmost constituent was omitted, resulting in *remoto* or *fittacamere*.

"Lexical" errors were substitutions of the whole left constituent with another existing word (e.g., roccaforte, *cassa*forte), or with a 'semi word' (e.g., fangoterapia, *fisio*terapia; '*fisio*' is not an independent word in Italian). Only in a few instances (e.g.

Table 1
Age, gender, education, lesion site and performance on BIT conventional, BIT behavioural (total score, 'menu' and 'stories' partial scores) and Bells cancellation for each participant.

P	Age	G	Ed. (years)	Site of lesion	BIT conven. (X/146)	BIT behav. (X/81)	BIT menu (X/9)	BIT stories (X/9)	Bells (X/34)
1	63	M	5	Temporal	111	54	7	7	25
2	63	M	10	Fronto-temporo-parietal	103	48	5	5	20
3	89	M	8	Parieto-occipital	76	36	3	5	15
4	78	F	8	Temporo-parietal	29	10	0	0	0
5	51	F	8	Deep parietal	29	9	1	0	5
6	60	M	8	Parietal	33	15	0	0	6
7	50	F	8	Temporo-parietal	113	48	1	3	32
8	69	M	5	Temporo-parietal	118	57	9	5	29
9	64	M	5	Deep parietal	114	49	3	5	26
10	53	M	13	Temporo-occipital, talami	40	21	1	1	14
11	68	M	12	Fronto-temporo-parietal	110	45	7	5	21
12	74	M	8	Parietal	90	41	3	3	18
13	81	F	13	Fronto parietal	87	39	3	3	15
14	86	M	5	Parieto-temporal	29	9	0	0	0
15	66	M	13	Fronto-parietal	101	40	3	0	14
16	63	M	8	Temporo-parietal	108	52	9	5	20
17	59	F	12	Fronto-temporo-parietal	113	52	9	5	19
18	56	F	8	Deep parietal	33	9	0	0	0

P = patient; G = gender; Ed. = education; BIT = behavioural inattention test (conv. = conventional; behav. = behavioural); BIT menu and BIT stories = reading tests included in BIT behavioural; Bells = Bells test.

madrepatria, *padre*patria) the error resulted in a non-word (e.g. *padre*patria is not a real word, but *padre* is a real independent word).

"Visual-orthographic" errors were substitutions of a grapheme of the left constituent with another grapheme, deletions of a grapheme that was not in the leftmost part or insertions of graphemes (e.g. fangoterapia, *faulo*terapia; accalappiacani, *accapalappia*cani). These errors, resulting in non-words, are not speech-based (the patients' speech production was, of course, normal), but presumably derived from visual-orthographic difficulties.

Non-classifiable errors were other errors that did not easily fit into the other categories (e.g. bordovasca, *la*vasca; ceralacca, *malacca*; zootecnica, *bo*tecnica). They differ from other errors in several respects. For instance in "bordovasca/*la*vasca" there is the omission of the leftmost part "bordo", but also the intrusion of "*la*" that was not present in the target "bordo".

3. Results

With respect to noun–noun compounds, no participant made a greater number of errors with left-headed compounds than right-headed compounds, and only three (see Table 2) made an equal number of errors in left-headed and right-headed compounds. This trend was uniformly observed for each category of errors. No difference was found in the number of errors between lists where the word was centered according to physical length or to the morphemic structure. This result was probably due to the minimal variation between the conditions. Therefore errors in the two types of lists were considered together for statistical analyses.

Table 2
Number of lists administered and errors made by each participant on the leftmost component in left-headed and right-headed compounds.

Participant	Number of lists	Errors		Error percentage
		LH	RH	
1	1	0	1	0%, 3.6%
2	6	8	10	4.7%, 5.9%
3	1	2	5	7.1%, 17.8%
4	2	11	11	19.6%, 19.6%
5	6	9	11	5.3%, 6.5%
6	2	8	17	14.3%, 30.36%
7	2	1	8	1.8%, 14.3%
8	2	5	5	8.9%, 8.9%
9	2	1	2	1.8%, 3.6%
10	6	48	58	28.6%, 34.5%
11	4	1	7	0.9%, 6.2%
12	6	9	27	5.3%, 16.1%
13	2	2	8	3.6%, 14.3%
14	2	50	51	89.3%, 91.1%
15	2	5	6	8.9%, 10.7%
16	2	4	8	7.1%, 14.3%
17	2	7	7	12.5%, 12.5%
18	1	0	4	0%, 14.3%

A preliminary Wilcoxon paired test showed a significantly higher number of errors with right-headed noun–noun compounds compared to left-headed noun–noun compounds [$V = 700$, $p < 0.001$]. The level of impairment did not influence the discrepancy in performance between left-headed and right-headed compounds, i.e. the overall percentage of errors of each patient did not correlate with the difference in accuracy between right-headed and left-headed compounds ($r = 0.07$, $p = 0.78$).

Data were further analyzed through Generalized Linear Mixed Models (Baayen, 2008). In these models an outcome is described as the linear combination of fixed effects and random effects (Jaeger, 2008). In this study the outcome (i.e. the dependent variable) is the probability of correct reading of a compound. The fixed effects (or predictors) are all psycholinguistic variables (included as covariates), the categorical variable distinguishing types of stimuli (i.e. left-headed and right-headed compounds)[1] and the interactions between the categorical variable and the psycholinguistic variables. The random effects are participants and words. The inclusion of these random effects essentially means that the variability associated to these variables is taken into account in the model, preventing that results could be due to the performance of few participants, or on few words. The statistical procedure used in Generalized Linear Mixed Models allows to choose the model that better fits the data. This model was chosen by stepwise backward selection, starting from an initial model that included all of the relevant variables.[2] Non-significant variables were considered for exclusion from the model one at a time, starting with the variable with the lowest $|z|$. For the categorical variable, no effect was considered for exclusion if it belonged to a factor in which at least one level had a $p < 0.05$. Before dropping a variable considered for exclusion from the model, a likelihood ratio

[1] Noteworthy, the inclusion of covariates allowed also to deal with the imperfect matching of psycholinguistic variables given the limited number of Italian noun–noun compounds.

[2] Before entering the variables in the model, multicollinearity was checked. Variables were included together in a model only if not collinear. In the case of dangerous collinearity (found for example, between age of acquisition and familiarity) we adopted the following strategy: separate models were fit and the model with the best goodness of fit was chosen.

test was performed between the two models: one with and one without the given variable. The variable was definitely removed if it did not contribute to significantly improve the goodness of fit of the model, as assessed through a likelihood-ratio test. The final model, the one that better and more parsimoniously fits the data, included several parameters. The Intercept of the model (the expected probability when the compound is left-headed and when all other predictors are set to 0) was 0.41 [$z = 0.54$, $p = 0.58$]. The β coefficients were the following: for right-headed noun–noun compounds $\beta = -0.57$ [$z = -2.64$, $p = 0.008$], for frequency of the whole word $\beta = 0.17$ [$z = 2.79$, $p = 0.005$] and for familiarity of the first constituent $\beta = 0.25$ [$z = 2.21$, $p = 0.03$]. All other fixed effects were not significant. Finally, the variance for participant and word random effects in the model was 0.29 and 2.1, respectively. Indices of the goodness of fit indicated a satisfactory model [$C = 0.84$, Somers' $D = 0.64$]. Results from this model are to be interpreted as follows: the dependent variable is the probability of a dichotomous variable (i.e., the probability of reading correctly the compound). This probability is expressed in logits (see Jaeger, 2008): positive values indicate a probability higher than 50%, negative values indicate a probability lower than 50% and a value of 0 indicates a probability of 50%. The effect of every significant predictor is independent and the relation between the predictors is additive. That is, the prediction for the probability of correct reading is the sum of the effects of all significant variables (whole word frequency, first constituent familiarity and type of compound). Unlike the coefficients for covariates (that indicate slopes), the coefficient for the right-headed compounds in the model indicates the adjustment to the Intercept that should be made to obtain a prediction for right-headed compounds, when left-headed compounds are taken as reference level. Since the predicted value for left-headed compounds is 0.41, the predicted value for right-headed compounds is $0.41 + (-0.57) = -0.16$. However, in order to obtain a meaningful prediction, the other predictors need also to be taken into account.

Results from this analysis can be summarized as follow: (1) the probability of reading right-headed compounds correctly is lower than the probability of reading left-headed compounds correctly. (2) As the whole-word frequency increases, the probability of correct reading increases. (3) As the first constituent familiarity increases, the probability of correct reading increases.

Separate analogue analyses for each type of error confirmed a trend in the same direction of the overall analysis (i.e., a higher probability of success in reading left-headed compounds than in right-headed compounds), although it was not significant due to the limited number of observations.

4. Discussion

The main result emerging from this study is straightforward: patients with left-sided neglect dyslexia could read the leftmost part of a compound word better when it was the head component rather than the modifier. In the left position, the advantage for the head component was observed in all but three participants in this study and no participant showed the opposite effect. These findings agree with a very recent, unpublished experiment by Marelli et al. (2009) who showed a headedness effect in six neglect patients in a timed condition. The pervasiveness of this head superiority effect in the sample studied here is remarkable, since a number of patients (the proportion is not known at present) do not even show lexical effects, such as the word superiority effect, at all (e.g. Ellis, Flude, & Young, 1987; Subbiah & Caramazza, 2000). This result cannot be attributed to factors like frequency, familiarity, age of acquisition and imageability, since these effects were controlled or partialled out. It was also not due to a greater possibility of guessing the first component given the second component.

This finding, although expected, is not to be taken for granted. In the first place, it was not possible, in principle, to predict that the head rather than the modifier could be more easily spared when appearing on the left, i.e. the position most affected by neglect. The head brings the semantically most important information within the compound, but the modifier, as an independent word, is obviously as important as the head. In other words, there would be no reason for one word (the head word) to be more semantically salient than another (the modifier word), if not in the context of a compound. The head superiority effect, therefore, is due to a given word component functioning as the head of the compound.

This finding seems to be consistent with the dual route theories of processing for complex words (e.g. Baayen, Dijkstra, & Schreuder, 1997; Isel, Gunter, & Friederici, 2003). On the one hand, the fact that neglect affected compound words mostly respecting boundaries between the first and the second component seems to be a sign of decomposition in processing. On the other hand, the head superiority effect could not emerge if the patients were not at the same time processing the whole word.

This suggests that attention is captured by the head component after implicit reading of the whole word. The head would require a relatively lighter processing load than the modifier and benefit from top-down facilitation (see Brand-D'Abrescia & Lavie, 2007 and Lavie, 1995, for a comprehensive theory of the working of attention in word recognition). Thus, the reading of compounds is easier for patients with neglect dyslexia when the head is on the left. Right-headed compounds are instead more vulnerable in this condition. Their leftmost component, the modifier, appears to be more prone to competition from distracters and hence more easily substituted when not omitted altogether.

The distribution of omission and substitution errors found in this study deserves a further comment. In the context of neglect dyslexia, it has been argued (Làdavas, 1998) that addressed phonology (the routine reserved for already known words) is less affected than assembled phonology (reading made on the basis of sublexical mechanisms like grapheme-to-phoneme conversion, which must be used for nonwords), thus explaining the lexicality effects. Participants in this study, most of whom showed the headedness effect, made more substitution and (less frequently) omission errors than phonological errors. In a minority of occasions, phonological errors may reflect an attempt to use assembled phonology rather than addressed phonology. Nevertheless, these errors also seem to affect modifiers more than heads in the leftmost position, which is a lexicality effect. Therefore, it is possible that assembled phonology is activated when addressed phonology fails.

Thus, the mental representation of compound words honours the respective roles within the internal structure of the compound, within which the head proves to be the most salient component. This seems to be consistent with recent electrophysiological findings. El Yagoubi et al. (2008) measured ERPs in normal participants to compare lexical decisions on left-headed and right-headed compounds. A significant difference emerged between left- and right-headed compounds at P300. In particular, right-headed compounds showed a more positive peak than left-headed compounds. Regarding the functional significance of polarity (with a more positive-going peak for right- than for left-headed), El Yagoubi et al. (2008) offered a number of interpretations worth noting here. In the first place, left- and right-headed compounds can differ in terms of the amount of attentional resources that they require. Indeed, the amplitude of P300 varies according to the amount of attentional resources invested in processing relevant stimuli (see Kok, 2001, for a review). One reason for right-headed compounds requiring more attention may be related to the fact that Italian right-headed compounds have a relatively less canonical order than left-headed compounds. Italian left-headed noun–noun compounds, in fact, reflect the order of grammatical classes normally found in Italian sentences, where the noun precedes the modifier. In contrast, right-headed compounds, although productive, do not reproduce the canonical order of syntax (they either originated from Latin or were built on an imitation of words from other contemporary languages, most frequently from English which only has right-headed compounds). It is thus possible that right-headed compounds require more attentional resources for processing with respect to the other two categories. Moreover, according to the so-called context-updating theory of Donchin and Coles (1988), the amplitude of the P300 is thought to reflect the processes by which information is updated in working memory as a function of incoming contextually relevant information. Since Italian has two positional options for the head, updating would take place with the right-headed compounds. That is, while the left component is 'automatically' recognized as the head, its information needs to be updated when the right component is processed and recognized as the proper head. This would result in an increase of the P300 amplitude.

In conclusion, evidence from neglect patients agrees with electrophysiological studies in highlighting how attention acts on the processing of compound words. The head component seems to attract selective attention more than the modifier, and in a different fashion.

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