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Lexical Constraints on Reading Accuracy in Neglect Dyslexia

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To elucidate the contribution of attention to reading, a detailed analysis of the performance of a right-brain-damaged patient with neglect dyslexia was conducted. Four-letter words and legal nonwords were presented to the right of ocular fixation for overt naming. More neglect errors occurred with nonwords (60%) than with words (15%). A significant majority of words produced on neglect errors to lexical targets had a higher frequency than the target. Lexical properties of the stimulus affecting neglect error rates were also studied. Examination of a particular source of effect was performed by isolating it from the possible effects of covariates through multidimensional matching. Word frequency had no effect on the rate of neglect errors. However, an increased number of orthographic neighbours that are of a higher frequency than the target and overlap it on their last three letters markedly increased neglect error rates. Neglect errors to words also increased if the first letter of these orthographic neighbours was visually similar to the first letter of the target. Neighbours with a lower frequency than the target had no effect. These results suggest that attention may act on low-level visual mechanisms involved in the encoding of letter shapes. Partial encoding of the letters constituting the target may lead to the activation of lexical representations. This lexical activation tends to be captured by high frequency words compatible with the correctly encoded portion of the stimulus.

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INTRODUCTION

A frequent effect of acquired brain damage is the disorder of visual hemineglect (De Renzi, 1982; Friedland & Weinstein, 1977; Hécaen & Angelergues, 1963; Heilman, Watson, & Valenstein, 1985; Kinsbourne, 1987; Robertson & Marshall, 1993; Roy, Reuter-Lorenz, Roy, Copland, & Moscovitch, 1987). Its essential feature is that patients tend to ignore the stimulation contralateral to the site of the lesion. This deficit can be seen in patients without hemianopia (Albert, 1973; Hécen & Angelergues, 1963). In contrast, cases with hemianopia only perform an active search of the contralesional visual hemifield and therefore do not show neglect provided exposure durations are sufficient to allow for eye movements (Bisiach, Capitani, Luzzatti, & Perani, 1981; Chédru, Leblanc, & Lhermitte, 1973; Ishiai, Furukawa, & Tsukagoshi, 1987; Meienberg, Zangemeister, Rosenberg, Hoyt, & Stark, 1981). Accordingly, several authors have attributed visual neglect to a deficit in the allocation of attention to the contralesional part of space (e.g. Heilman et al., 1985; Kinsbourne, 1970; Mesulam, 1981, 1983; Morrow & Ratcliff, 1988; Riddoch & Humphreys, 1987; Roy et al., 1987; but see also Bisiach & Berti, 1987; Bisiach, Luzzatti, & Perani, 1979; for a different interpretation). The localisation of brain damage most commonly associated with visual hemineglect is right parietal (Bisiach et al., 1979; Critchley, 1953; De Renzi, 1982; Heilman et al., 1985; Mesulam, 1981; Vallar & Perani, 1986; 1987), although neglect symptoms have been observed following lesions to several other cortical and subcortical sites (Damasio, Damasio, & Chui, 1980; Healton, Navarro, Bressman, & Brust, 1982; Heilman & Watson, 1977; Heilman et al., 1985; Mesulam, 1981, 1983; Vallar & Perani, 1987

A reading disorder that is often observed in patients with visual neglect is neglect dyslexia. In this disorder, reading is compromised by frequent errors affecting the contralesional portion of either single words or text (Arguin & Bub, 1992; Baxter & Warrington, 1983; Behrmann, Moscovitch, Black, & Mozer, 1990; Brunn & Farah, 1991; Caramazza & Hillis, 1990a, 1990b; Costello & Warrington, 1987; Ellis, Flude, & Young, 1987; Kartsounis & Warrington, 1989; Kinsbourne & Warrington, 1962; Patterson & Wilson, 1990; Riddoch, Humphreys, Cleton, & Fery, 1990; Siéroff, 1990; Siéroff, Pollatsek, & Posner, 1988; Tegnér & Levander, 1993; Young, Newcombe, & Ellis, 1991). It has long been thought that neglect dyslexia was an integral component of the visual hemineglect syndrome, due to the co-occurrence of the disorders and the similarity of the symptoms. More recently however, this view has been challenged by observations of neglect dyslexia in the absence of neglect symptoms for nonverbal materials (Baxter & Warrington, 1983; Patterson & Wilson, 1990; Riddoch et al., 1990) and by neglect dyslexia for one side of space and neglect for nonverbal materials for the opposite side of space (Costello & Warrington, 1987; Cubelli, Nichelli, Bonito, De Tanti, & Inzaghi, 1991).

Manifestations of neglect dyslexia as well as the stimulus properties that affect performance vary greatly from one case to another (Ellis, Young, & Flude, 1993; Riddoch, 1990). For instance, whereas several neglect dyslexics are impaired in reading isolated words and text (Behrmann et al., 1990; Caramazza & Hillis, 1990b; Ellis et al., 1987; Kinsbourne & Warrington, 1962; Riddoch et al., 1990; Warrington, 1991; Young et al., 1991), others show a deficit only with isolated words (Costello & Warrington, 1987; Patterson & Wilson, 1990; Riddoch et al., 1990). Similarly, whereas neglect dyslexia symptoms are most acute with nonwords but weaker or nonexistent with words in some patients (see review following), others show no such effect of stimulus lexicality (Ellis et al., 1987). Given this variability, it appears improbable that a single locus of functional impairment may account for all cases of neglect dyslexia, even though most authors do agree on the fact that the disorder is to be attributed to some form of impairment in the spatial allocation of attention. From this viewpoint, it appears that a central contribution of the study of neglect dyslexia should concern our knowledge of the role spatial attention may play in reading, the level(s) of processing where it acts, and the way attention and stored lexical knowledge interact.

Attention and Reading

Given the existence of neglect dyslexia and the commonly held assumption that it results from a faulty allocation of spatial attention to one side of the stimulus, the straightforward conclusion would be that attention does play an important role in normal reading. However, a thorough review of the literature on normal observers by McCann, Folk, & Johnston (1992) notes that contradictory results have been obtained across studies in a variety of experimental paradigms. Thus, whereas some experiments provide evidence for a contribution of spatial attention to reading, others show results suggesting that word recognition is automatic, i.e. attention-free. According to McCann et al., these inconsistencies mainly find their explanation in the poor control over the locus of spatial attention that has been afforded by the methods used in a number of studies. In their own work, McCann et al. have used spatial cueing and filtering paradigms in the context of a lexical decision task to determine if attention contributes to reading. Their observations indicate spatial cueing effects and filtering costs on the time required to perform the lexical decision, and that these effects are the same for high- and low-frequency words and for nonwords.

Assuming that spatial attention does play a role in reading, one outstanding question is the particular level of processing it affects. Many early selection theories—i.e. those that predict an attentional contribution to word recognition—assume that either feature encoding or the transfer of feature information to a letter recognition mechanism is the attention-sensitive process (see McCann et al., 1992). Although clear evidence exists that attention indeed affects early visual mechanisms (Hillyard, Mangun, Worldorff, & Luck, 1995; Moran & Desimone, 1985), such demonstrations specifically regarding reading still need clarification, as indicated later. Cumulative evidence from cases of hemispatial neglect suggests that several levels of representation in visual processing, and therefore in reading as well, may be affected by attention.

Marr (1982; Marr & Nishihara, 1978; see also Feldman, 1985) has proposed that the initial encoding of a visual image is performed by what he called the primal sketch, which is a retino-centric representation mediating the registration of local stimulus features and their grouping. This information would then be forwarded to the 2½D sketch, which is a viewer-centered representation performing an explicit coding of the orientation and depth of visible surfaces. Finally, the 3D model is proposed as an object-centered system responsible for the representation of the volumetric primitives constituting an object and the way they are attached to one another.

An analogous proposal has been made by Caramazza and his collaborators with specific reference to reading (Caramazza & Hillis, 1990b; see also Rapp & Caramazza, 1991; Monk, 1985). Initial encoding of orthographic stimulation would proceed through a feature map, representing edges in the image within a retino-centric spatial coordinate frame. The letter shape map is then proposed to specify the shapes defined by the edges encoded in the preceding stage and to represent the spatial relations among the various parts of the stimulus in a stimulus-centered reference frame. Finally, the grapheme description derives an abstract orthographic representation of the stimulus that is independent of letter shape as well as of stimulus orientation. It is through this last stage that stored lexical-orthographic knowledge can be addressed from a visual input.

In relation to these theoretical proposals, a number of studies of patients with visual neglect (using either written or graphic stimuli) have provided evidence for multiple dissociable spatial reference frames that can separately be affected by the attention deficit (Arguin & Bub, 1993; Behrmann & Moscovitch, 1994; Calvanio, Petrone, & Levine, 1987; Caramazza & Hillis, 1990a, 1990b; Farah, Brunn, Wong, Wallace, & Carpenter, 1990; Làdavas, 1987; Làdavas, Del Pesce, & Provinciali, 1989). In addition to contributing evidence for multiple spatial reference frames, these latter studies have shown that attention may affect a number of different levels of visual processing.

With specific reference to reading, evidence from neglect dyslexia indicates that attention may affect low-level visual processing. For instance, it has been shown that the reading performance of some neglect dyslexics is modulated by the lateral placement of the target relative to the point of ocular fixation even within the non-hemianopic visual field (Behrmann et al., 1990). According to theories such as those described earlier, these observations would indicate that the spatial reference frame affected by the attention deficit operates on retino-centric coordinates and is responsible for the encoding of the features by which letter shapes are internally described (i.e. the “feature map”; Caramazza &

Hillis, 1990b; Rapp & Caramazza, 1991). Although the point that the lateral placement effect stems from a deficit at a retino-centric level is indisputable, no study has yet examined whether the encoding of letter features may actually be impaired in neglect dyslexia or whether the reading deficit originates from a higher order of representation of the orthographic input. On a theoretical level, a retino-centric deficit is expected to also mean a deficit in feature encoding. However, the assumption that the registration of the visual features characterising the visual input may be affected in neglect dyslexia still needs empirical verification. The present study will address this issue.

The Interaction of Attention and Lexical Knowledge

One important finding to emerge from research on neglect dyslexia in recent years is that, in several patients, neglect errors are much less frequent when the stimulus is a word than when it is a pseudoword or a random string of letters (Arguin & Bub, 1992; Behrmann et al., 1990; Brunn & Farah, 1991; Caramazza & Hillis, 1990b; Patterson & Wilson, 1990; Riddoch et al., 1990; Siéroff et al., 1988). This indicates that stored lexical knowledge may serve to compensate at least partially, for the attention deficit. A wide variety of explanations have so far been proposed for the way in which this compensation may take place.

One such account simply assumes that neglect dyslexics are more likely to infer, or guess, the neglected portion of a word than a nonword due to the orthographic constraints of written language (Patterson & Wilson, 1990). For instance, if a patient has been able to determine that the last three letters of a four-letter string are "I-R-D," the only word that corresponds to this letter pattern is "BIRD." In contrast, any letter other than "B" can occupy the first location in the letter string if it is a nonword. The crucial point in this account is that the patient is explicitly using lexical orthographic knowledge to infer the identity of the neglected portion of the stimulus. This predicts that neglect dyslexia patients who do show a word superiority effect should also show evidence for a strong bias towards producing responses that are words. Lack of such a bias, in contrast, would indicate that the patient is not explicitly tapping into his lexical knowledge to guess the neglected portion of stimuli.

The orthographic constraints provided by stimulus lexicality have led Caramazza and Hillis (1990b) to propose another account, which does not assume any inferential process such as that suggested by Patterson and Wilson (1990). Indeed, according to Caramaza and Hillis, the accurate encoding of the letter identities of the non-neglected portion of a word may be sufficient to address its internal lexical representation adequately and thereby to recognise it correctly. Thus, on the basis of this partial lexical access only, more word than nonword targets could be reported correctly. In contrast to the previous account, the theory proposed by Caramazza and Hillis does not *require* a word superiority effect in neglect dyslexic patients to be accompanied by a word bias at response selection. However, the observation of such a bias may remain compatible with the theory if it is assumed that nonwords that are orthographically similar to real words often activate lexical representations sufficiently to trigger a “word” response. Another important aspect of the account of Caramazza and Hillis is that the activation of a lexical representation by the input has no effect on the quality of letter encoding or on the spatial distribution of attention over the stimulus—in contrast to the other accounts described later. This assumed invariance of low-level processes across words and nonwords predicts that, even though a quantitative performance advantage may be found for words, the properties of the errors observed (e.g. lexicality of the errors) and the various stimulus variables that may affect the rate of neglect errors (e.g. orthographic neighbourhood size; see following) should not vary as a function of stimulus lexicality only.

Another class of account for the word superiority effect in neglect dyslexia rests on the assumption that activation of lexical orthographic knowledge automatically results in feedback to lower-level operations whose effectiveness would thereby be increased. One such explanation is directly inspired by McClelland and Rumelhart’s (1981) interactive activation model of word recognition. One main motivation for this model was to explain the superior identification of briefly exposed letters by normal observers if they are presented within words than when they are displayed in isolation or within nonwords (Reicher, 1969; Wheeler, 1970). According to the model of McClelland and Rumelhart, the activation of lexical representations automatically results in facilitatory feedback to units responsible for letter encoding, thus leading to an improved identification of letters if they are part of a word. This feedback mechanism from lexical representations to lower-order units has been invoked by Siéroff et al. (1988) and Behrmann et al. (1990) to explain the word superiority effect in neglect dyslexia (see also Mozer & Behrmann, 1990). Under this top-down facilitation hypothesis, the representation of the letters constituting the neglected portion of the stimulus that is derived by letter encoding units would be more accurate with words than nonwords. This contrasts with the probabilistic accounts described earlier. One clear prediction that follows from this is that if a word superiority effect occurs in neglect dyslexia, stimulus lexicality should also result in qualitative changes in result patterns. In particular, since the reading process is modified by stimulus lexicality, the properties of the errors observed and/or the effects of some stimulus variables on accuracy should differ between word and nonword targets.

Another possible top-down process that has been proposed as the source of the word superiority effect in neglect dyslexia is that orthographic lexical access may feed back on a low-level attention mechanism such that it would be realigned to encompass the entire length of the letter string (Brunn & Farah, 1991). As with the word-to-letter feedback hypothesis, the explanation proposed by Brunn and Farah assumes that the signal derived by the letter encoding operation would be improved by the lexical status of the stimulus. The predictions made by the "word-to-letter feedback" hypothesis described above are also covered by the account of Brunn and Farah. However, the latter explanation also implies, in contrast to those described previously, that the lexical status of the stimulus (word/nonword) must be recognised prior to the accurate identification of the target in order to trigger a realignment of attention. It would seem then that the hypothesis of lexical modulation of the distribution of spatial attention should predict that, in cases of errors, there should be a bias for the response produced to have the same lexical status as the target.

Obviously, the proponents of each of the explanations described here for the word superiority effect in neglect dyslexia have provided evidence compatible with their view. However, the available data fails to support one of these accounts specifically while excluding all others. Admittedly, a unique account of the phenomenon for all cases may not be possible in light of the multiplicity of functional impairments that may cause neglect dyslexia. One must point, however, that the occurrence of the word superiority effect in neglect dyslexia is likely to be a direct function of the residual capacities of what was once a normal reading system; not that of the functional deficit suffered by the patient. Because of this, and assuming minimal uniformity in the functional properties of the reading mechanisms of different neurologically intact individuals, one must consider the prospect of a common origin to the word superiority effect in the different neglect dyslexic patients who show it. The observations reported here are relevant to the issue. With respect to the patient studied here, it will be shown that an explanation of her performance requires the assumption that access to lexical orthographic knowledge occurred even with partial encoding of the letters constituting the stimulus. As well, the results suggest that this lexical access resulted in facilitatory feedback to letter-level representations, thereby contributing to a reduction of neglect errors to words relative to nonwords. Specific aspects of the results are incompatible with other accounts of the word superiority in neglect dyslexia.

Outline

One crucial operation that a normal recognition system must be able to perform is to provide the unique mapping of an encoded stimulus to stored knowledge about the world. With respect to visual word recognition, this implies that the orthographic string has to be encoded and put in correspondence with stored knowledge about a single known word; other related (e.g. visually or orthographically) items must at some point be eliminated from the competition the mapping operation involves. The competitive nature of the process means that the way in which a particular target item relates to other stored representations may have an effect on reading performance. Such effects have previously been documented with respect to reading in neurologically intact individuals. In particular, it has been shown that orthographic neighbours to a target (other words that overlap the target on all letters but one; Coltheart, Davelaar, Jonasson, & Besner, 1977) may be activated by the display and that this activation affects the time and accuracy with which the target is identified (for reviews see Andrews, 1992; and Grainger, 1992). Similarly, Riddoch et al. (1990) and ourselves (Arguin & Bub, 1992) have previously shown that words with many orthographic neighbours result in increased error rates in neglect dyslexia. In addition to standard analyses of error types and of the effect of target lexicality, the present paper reports the study of orthographic neighbourhood effects in a patient with neglect dyslexia in order to uncover some of the constraints that determine reading performance in this disorder. The patient, EB, was presented with a large number of words and pseudowords for reading aloud and accuracy was measured. Properties of the errors made by EB as well as the effects of a number of variables concerning the way in which a particular target relates to stored lexical-orthographic knowledge on reading accuracy were analysed. The results highlight the competitive nature of the recognition process involved in reading and allow us to elucidate some aspects of the effect of a lateralised visual attention deficit on orthographic encoding. Specifically, it will be shown that neglect error rates to words are increased if the target has many higher-frequency orthographic neighbours differing from it on their first letter, as well as when such neighbours are highly similar visually with the target. By contrast, lower-frequency neighbours have no effect on neglect error rates. In addition, neglect error rates to nonwords increased markedly when the target had many lexical neighbours differing from it on their first letter compared to when the item had no such neighbours.

CASE REPORT AND METHOD

Subject. EB was a right-handed anglophone housewife aged 89 at the time of testing. Her symptoms started four years earlier when she suddenly experienced visual distortions. Looking at herself in a mirror, she had the impression that one of her eyes was higher than the other and that parts of her face were deformed. A CT scan conducted 1 month after this episode showed diffuse cortical atrophy but no focal lesion. However, an EEG revealed a moderate anomaly over the right temporal area extending above the Sylvius fissure. A neurological examination suggested a dense left homonymous hemianopia (Goldmann perimetry) but otherwise, no important sensorimotor symptom. EB had no apparent language impairment; she talked fluently and showed excellent oral comprehension. The patient complained of difficulties in perceiving visual motion: She felt as if moving objects moved toward her, even if this was not their real trajectory. The optokinetic nystagmus was normal, however. The patient also had prosopagnosia, without any problem in colour perception. EB's visual acuity was low (20/70 on each eye) and, according to her reports, was only partially corrected by eyeglasses. No data is available on her actual corrected visual acuity. EB showed no evidence of ocular disease. She showed severe visual neglect on the bells test (Gauthier, Dehaut, & Joanette, 1989), on which she scored 12/35. The only targets she could detect were those on the right side of the page on which stimuli were displayed. A previous study of EB's reading performance (Arguin & Bub, 1992) is now summarised. The patient showed severe neglect dyslexia. With 1sec stimulus exposures, she exhibited a large asymmetry on the accuracy with which she reported the left- and right-hand sides of words and nonwords, with error rates of 42% and 11% on the left and right, respectively. She also showed a word superiority effect similar in form to what had been observed previously in other neglect dyslexic patients, with error rates of 13% and 70% in reporting the left side of words and nonwords, respectively. Neglect error rates to words reduced with increasing word frequency but increased as a function of the number of orthographic neighbours that were higher in frequency than the target. In a partial report task with stimuli exposed for 300msec, EB's identification of the leftmost letter of words was superior to that of pseudowords or random letter strings. However, she made frequent localisation errors on the leftmost letters of words that she accurately identified. Testing of EB's reading of long words (six letters or more) printed vertically showed perfect performance. There was therefore no evidence for word-centred neglect dyslexia, a disorder whose features remain unchanged by stimulus orientation (Caramazza & Hillis, 1990a, 1990b). The patient's writing of single words to dictation was also intact.

Stimuli and Materials. The stimuli were 870 words and 469 nonwords. All items were four letters long and were displayed in upper case. They were printed in a large (24-point) bold font due to the reduced visual acuity of the subject. The words were selected from a crossword puzzle dictionary and their frequencies ranged from 1 to 12,458 per million words (Francis & Kucera, 1982). The nonwords were made by changing one letter of a four-letter word such that the item remained pronounceable and that it was roughly matched to the base word on single-letter and bigram frequencies (Mayzner & Tresselt, 1965). The average frequencies of constituent letters and bigrams were, respectively, 455 and 59 for words, and 427 and 51 for nonwords. Words and nonwords were also matched on two other important properties: (1) the number of words that can be made from the stimulus if the subject fails to encode its first (leftmost) letter and only processes the last three [131/870 for words, 86/469 for nonwords; $\chi^2(1) = 3.29$; n.s.]; (2) the number of words that can be made from the stimulus if the subject substitutes the first (leftmost) letter for another letter [averages: words = 3.3, nonwords = 3.2; $t(1322) = 0.75$; n.s.]. The stimuli were presented on the screen of a Macintosh computer controlled by PsychLab software (Bub & Gum, 1995).

Procedure. Each trial began with a 1500 msec fixation point presented at the centre of the display screen. Its offset was immediately (0msec interstimulus interval) followed by a target word or nonword whose left end was aligned 1cm to the right of the fixation function. The target remained on for 500msec. This stimulus duration was determined after pilot testing with 750msec stimulus exposures, which showed error rates too low to yield any major effect of stimulus properties on performance. EB was instructed to report the target as accurately as possible either by reading it aloud or by reporting as many letters as could be identified. Actually, the patient very rarely (less than 2% of trials) produced a "letter-by-letter" report spontaneously; rather, her responses were attempts to name the entire string. On occasion, the way in which this naming response should be spelled was ambiguous. When requested by the experimenter, EB was always capable of producing a "letter-by-letter" report congruent with her previous naming response. EB was informed that she could take her time to respond and that there was no time constraint for response production. Overall, her average response time was of 1279msec. The experimenter recorded responses and then triggered the next trial when the subject was ready with her eyes directed at the fixation point. Words and nonwords were distributed randomly across 20 blocks of 69 or 70 trials, each comprising 24 or 25 nonwords. The complete experiment was run in 7 testing sessions conducted over a 2-month period.

RESULTS

Data analyses proceeded in two main stages. The first examined the effect of stimulus lexicality on error rates and on the kind of neglect error (i.e. error affecting the leftmost portion of the stimulus—the first two letters of the four-letter strings) that is produced. The second stage of data analysis examined the effect of word frequency and of the relation between the target and other words on the rate of neglect errors. With two exceptions, all analyses are based on the numbers of trials on which an error was produced, with every trial counted only once. The two exceptions concerns analyses in which we examined the stimulus locus concerned by an error (right vs. left portion of the item) and the class of neglect error (omission, substitution, or addition). In both cases, at least some combinations of error kinds are not mutually exclusive (e.g. an error may affect both the left and right portions of an item); therefore some trials on which an error was observed could be counted twice in those analyses.

Error Properties and Lexicality

Overall, EB made 433 errors (an incorrect response was produced on 423 trials) out of the total of 1339 trials that were run. Congruent with the prior diagnosis of EB as suffering from neglect dyslexia, the distribution of these errors is greatly asymmetric across the left and right portions of the stimulus. Thus, 414 errors affected the left portion of the items (first 2 letters; 30.9% errors) whereas only 19 errors affected the right (last 2 letters; 1.4% errors). This difference is highly significant [$\chi^2(1) = 429.8$; $P < .0001$].

Stimulus lexicality also had a major effect on accuracy, with words leading to many fewer neglect errors than nonwords (Fig. 1). Thus, while EB's error rate on the left portion of words is only 15.1%, that on the left portion of nonwords is 60.3% [$\chi^2(1) = 292.6$; $P < .0001$]. This result indicates a word superiority effect on EB's neglect dyslexia of the same kind as that reported previously in several other patients with the same disorder. The error rate difference between words and nonwords was also significant for the rightmost portion of the stimuli (words = 0.46% errors; nonwords = 3.2% errors; [$\chi^2(1) = 16.3$; $P < .0001$], but this difference was substantially weaker (error rate difference of 2.7%) than that on the leftmost portion of the items (error rate difference of 45.2%) and it only involved a small number of observations (overall, a total of 19 errors were made on the rightmost portion of stimuli).

Despite the large effect of stimulus lexicality on the rate of neglect errors, this factor had no measureable influence over features of the neglect errors produced by EB.

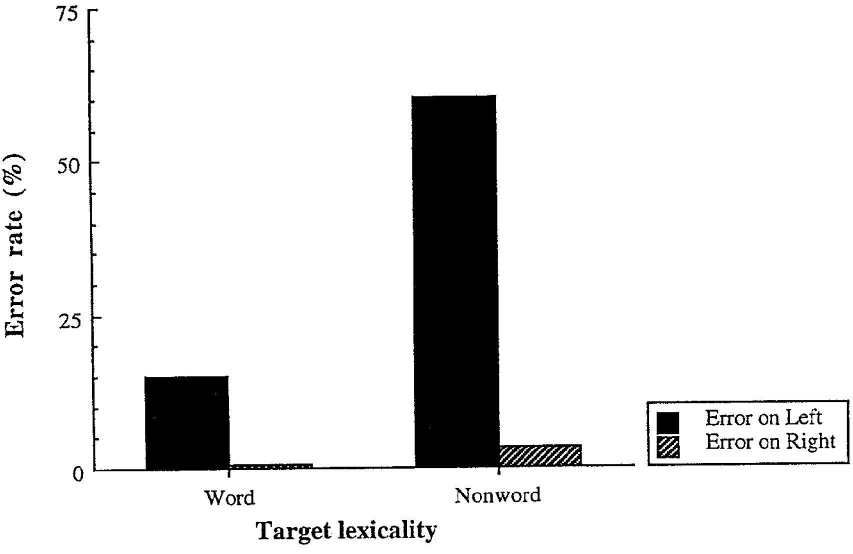

FIG. 1. Percentage of errors as a function of target lexicality and stimulus side.

Figure 2 shows that the lexicality of the responses produced on neglect errors is identical across word and nonwords stimuli [$\chi^2(1) = 0.0002$; n.s.]. It may be noted in Fig. 2 that neglect error responses were more often words than nonwords [$\chi^2(1) = 10.52$; $P < .01$]. This result indicates that EB was biased to produce a word as response when she failed to identify the item correctly. This bias may suggest a "guessing" account (Patterson & Wilson, 1990; see earlier) for the patient's reduced rate of neglect errors with words relative to nonwords. An alternative interpretation of this bias, however, is that it may be a reflection of the probability of the stimulus being a word (see e.g. Davison & Tustin, 1978; Green & Swets, 1966; Macmillan & Creelman, 1991; for relevant discussion). Indeed, while a word response occurred on 58% of neglect errors, the probability in the stimulus set used of the target being a word is 65%. Unambiguous support for a guessing strategy in EB would have required a word bias that is greater in the error responses than in the stimulus set, whereas here we observe a trend in the opposite direction. Other aspects of the results discussed later also militate against the hypothesis of the patient using a guessing strategy.

The analysis of neglect errors was pursued by examining whether the class of neglect error produced varied as a function of stimulus lexicality. Three neglect error classes were examined, which were divided according to whether the error produced involved the *omission* of one or two of the leftmost letters of the item (e.g. target = DARK; response = ARK), the *substitution* of one or two of these letters by others (e.g. target = SLIP; response = SNIP), or the *addition* of one or more letters to the left portion of the target (e.g. target = FUSE; response = REFUSE). Except for the pair omission-addition, these error

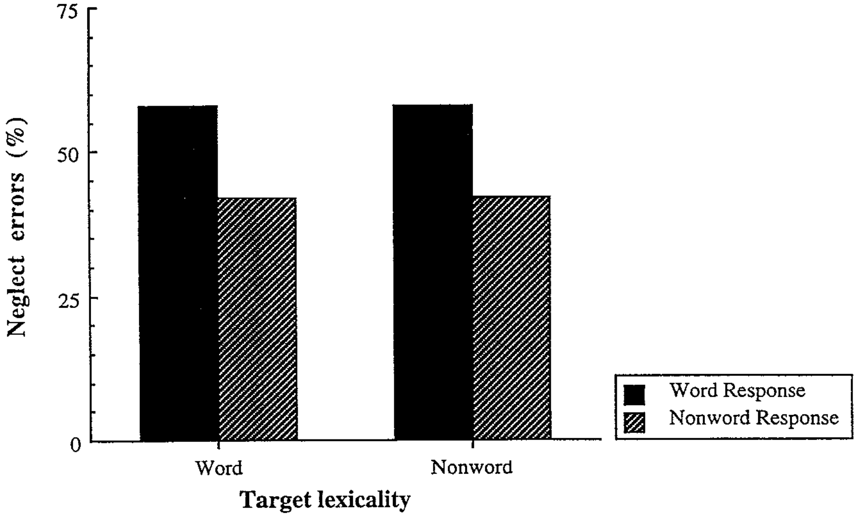

FIG. 2. Distribution of neglect errors to word and nonword targets as a function of response lexicality.

classes are not mutually exclusive. The distribution of neglect errors across these classes did not differ as a function of whether the target was a word or a nonword [Fig. 3; $\chi^2(2) = 0.16$; n.s.].

What the results on the lexicality and class of neglect errors suggest is that the process by which EB encoded the stimuli was not changed by the lexicality of the item; i.e. there is no evidence in these data suggesting that a special operation that would contribute to EB's reading performance is triggered by stimulus lexicality. In contrast, we note on Fig. 3 that the class of neglect error varied markedly with the lexicality of the *response* produced by EB [$\chi^2(2) = 97.7$; $P < .001$]. Thus, while substitution errors (60.0%) were much more frequent than omissions (34.5%) if the neglect error produced was a word, the opposite pattern was observed if the neglect error was a nonword (substitutions = 15.8%; omissions = 82.1%). Otherwise, addition errors were rare and their frequency varied little across neglect errors where the response was a word or a nonword.

Overall, the dominant neglect error class in EB is that of omissions, which occurred on 57.7% of neglect errors, compared to 44% for substitutions (it should be recalled that those error classes are not mutually exclusive). This result is at variance with other reports that showed a strong tendency for substitutions to be the most common class of neglect error (Behrmann et al., 1990; Ellis et al., 1987; Kinsbourne & Warrington, 1962; Patterson & Wilson, 1990; Riddoch et al., 1990; Tegnér & Lavendar, 1993; Warrington, 1991). This dominance of substitution errors has been taken as evidence that neglect dyslexics, although often unable to identify the letter(s) on the neglected portion of the item, may nevertheless be capable of registering the accurate length of

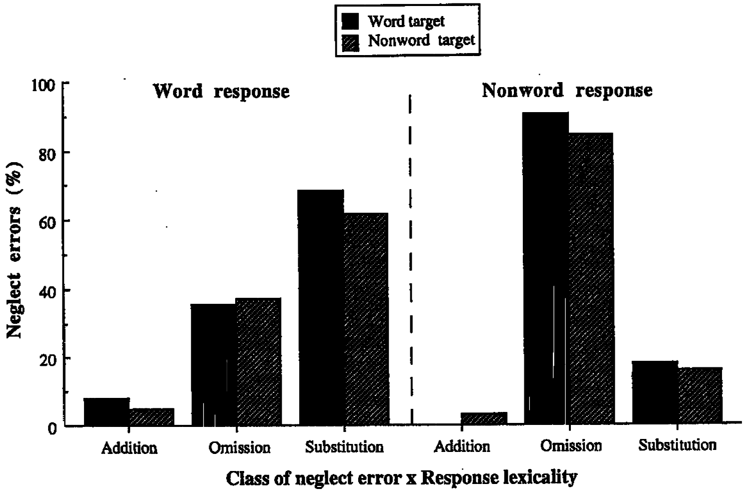

FIG. 3. Distribution of neglect errors to word and nonword targets as a function of class (addition/omission/substitution) and response lexicality.

the stimulus (Ellis et al., 1987). EB seems to have had difficulty doing so since she made more omission than substitution errors. It seems unlikely that this trend is an artefact of allowing the patient to identify the target by reporting its individual letters rather than to name the word or nonword, because she spontaneously used a sequential letter report only very rarely (on less than 2% of trials). The dominance of omission errors is also unlikely to be related to exposure duration since the same phenomenon has been observed previously in a similar experiment where stimuli were exposed for a 1sec duration (Arguin & Bub, 1992) instead of the 500msec duration used here. Rather, it appears that the result is a true reflection of EB's visual encoding capacity and therefore, that if a dominance of substitution errors really denotes the preserved ability of accurately registering the length of the letter string (see Discussion on this point), this kind of sparing is not universal among neglect dyslexics. Another noteworthy point regarding the fact that omissions are the most common class of neglect error is that this result is surprising when one considers the context of the present experiment. Indeed, all the items used were four letters long, the patient was reminded of the fact regularly, and on being reminded, she consistently indicated she was well aware of the fact. This would suggest that EB adopted a somewhat conservative criterion in the responses she produced and that she did not venture a guess in case of uncertainty. In other words, it appears that her responses correspond to what she actually perceived of the stimuli rather than to some form of deductive reasoning aimed at completing what she knew to be a partial encoding of the item.

One last aspect of EB's neglect errors that is of interest concerns the relative frequencies of the target and the response she produced when both items were words. On 69.9% of these neglect-error trials, the response corresponded to a word with a higher frequency than the target. The probability of such a distribution by chance alone (binomial test conducted under the assumption of a 50% chance rate of producing a word with a frequency higher than that of the target) is 0.04%. Actually, the assumption of a 50% chance rate of producing a word with a frequency higher than that of the target may be extremely conservative. Indeed, if we consider the frequencies of the words on which EB made a neglect error, and produced a word as response against the frequencies of all the four-letter words available in our word frequency list ($N = 1829$), the chance probability for any four-letter word being more frequent than the target is 36.8%. A similar comparison, performed this time against the frequencies of all words that share their last three letters with the target ($N = 2366$), yields a chance probability of 25.7% of producing a response that is a word more frequent than the target. In agreement with the observation that words produced on neglect errors are often more frequent than the target, we note that, on average, the words produced on neglect errors to a target word had a frequency that was 201.9 points (median difference = 23) higher than the stimulus presented [$t(73) = 3.1$; $P < .005$]. These results suggest that, if EB failed to process the leftmost part of a word correctly, the response produced was constrained by the orthographic information she had been able to encode from the rightmost part of the item. High-frequency words congruent with the rightmost portion of the stimulus then tended to be favoured over words with a lower frequency. The analyses reported in the next section provided evidence congruent with this hypothesis.

Word Frequency and Relation between the Target and Other Words

Analysis Procedure

As indicated previously, the second stage of data analysis examined neglect error rates as a function of word frequency and of the orthographic relations between the target and other words. With respect to the relational analysis, every item tested was labelled according to its numbers of lexical orthographic neighbours of various classes. When the number of a particular class of orthographic neighbours affected performance, a supplementary analysis was conducted to examine the effect of the visual similarity of the target with these neighbours. These constituted the variables whose effects were studied on the rate of neglect errors produced by EB.

Orthographic neighbours are words made of the same number of letters as a particular target and which differ from it by only one letter (e.g. CARE–DARE; Coltheart et al., 1977). With respect to word targets, four different orthographic neighbourhood size parameters were computed. These parameters are divided according to the relative frequencies of the target and a particular orthographic neighbour (higher or lower in frequency[1]) and according to the letter position by which these items differ (first or second letter[2]). Thus, the variables concerning orthographic neighbourhood size that were analysed for word targets are: number of orthographic neighbours that are of a higher frequency than the target and differ from it on their first (N1-HF) or second (N2-HF) letters, and number of neighbours that are of lower frequency than the target and differ from it on their first (N1-LF) or second (N2-LF) letters. With respect to nonword targets, the relative frequency of the target and its

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[1] In a small number of cases, orthographic neighbours had the same frequency as the target. These cases were arbitrarily counted as having a frequency lower than the target,

[2] It did not appear pertinent to examine the effects of orthographic neighbours that differed from the target on their third or fourth letter. Indeed, the dependent variable studied in these analyses is the rate of neglect errors. In a patient with left neglect such as EB, these errors exclusively concern the report of the first two letters of the four-letter items used here. It would be unlikely for neighbours differing from the target on their third or fourth letters to affect the rate of neglect errors. In fact, as will be seen later, orthographic neighbours differing from the target on their second letter had no effect on the rate of neglect errors.

orthographic neighbours was not a factor since, by definition, nonwords have a null frequency. Thus, the orthographic neighbourhood variables analysed for nonword targets are: numbers of neighbours that differ from the target on their first (N1) or second (N2) letters. For each of these variables, EB's rate of neglect errors was compared between items with no orthographic neighbour of one kind and items with a number of such neighbours.

In cases where orthographic neighbours were shown to affect performance, additional analyses were conducted to examine whether the visual similarity between those neighbours and the target had an effect on neglect error rates. Indeed, orthographic neighbours can be rated according to the degree of visual similarity of the letters that distinguish neighbour and target. For instance, the word pair BARE–DARE would be considered as more visually similar than CARE–DARE because the visual similarity between B and D is greater than that between C and D. The metric used to determine the visual similarity of targets and their orthographic neighbours was derived from a number of empirical letter confusion matrices, which were averaged (Gilmore, Hersh, Caramazza, & Griffin, 1979; Loomis, 1982; Townsend, 1971; Van Der Heijden, Malhas, & Van Den Roovaart, 1984[3]). Operationally, the visual similarity between a target letter and another letter of the alphabet is determined by the proportion of trials on which the target, presented briefly to normal observers, was misidentified for this other letter. The greater the value, the more similar the two letters are. To come back to the example (BARE–DARE vs. CARE–DARE), we note that the visual similarity[4] of target B to the letter D is 7.88 whereas that of target C to the letter D is only 0.93. The averaged visual similarities of targets to the orthographic neighbours of each of the classes described earlier served here as the supplementary independent variables, whose effects were studied. Thus, for word targets, the variables concerning the similarity of stimuli to their orthographic neighbours were: the visual similarity of orthographic neighbours that are of higher frequency than the target and differ from it on their first (VS/N1-HF) or second (VS/NS-HF) letters, and the similarity of neighbours that are of lower frequency than the target and differ from it on their first (VS/N1-LF) or second (VS/N2-LF) letters. For nonword targets, the neighbourhood visual similarity variables were: visual similarity of neighbours differing from the target on their first (VS/N1) or second (VS/N2) letters. Of course, the analysis of the effects of the visual

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[3] These studies only used upper-case letters, which is why the stimuli used here were printed in upper case. At the time the experiment was conducted, we were unaware of any published confusion matrix for lower-case letters, although one can be found in Jacobs, Nazir, & Otto (1989).

[4] Note that, to avoid using very small fractions in referring to the visual similarities between targets and their orthographic neighbours, and therefore to make the data more readable, a linear transformation was performed on the raw visual similarity values by multiplying these indexes by 100. This transformation is used throughout in this paper.

similarity of targets with their orthographic neighbours excluded items which have no orthographic neighbour.

Some of the variables whose effects on neglect error rates we studied tend to covary strongly. Possibly the best examples are the lexical frequency of a target and the numbers of orthographic neighbours that are of a lower or higher frequency than the target. Obviously, a word with a high frequency will tend to have fewer higher-frequency neighbours and more lower-frequency neighbours; vice versa for a low-frequency word. Previous studies conducted with normal observers have demonstrated the crucial importance of controlling for such covariations in examining a particular source of effect on reading performance (e.g. Grainger, 1990). To dissociate the effects of the different independent variables studied, groups of items were created that differ markedly on the variable whose effect we wanted to examine, but which are closely matched in a pairwise manner on other properties that characterise the items studied. For instance, to examine the effect of lexical frequency, two sets of words with substantially disparate frequencies were matched pairwise on the following variables: N1-HF, N2-HF, N1-LF, and N2-LF. By this procedure, the effect of a specific independent variable can be studied in isolation from the potential effects of other stimulus properties. The total number of pairs selected for each analysis depended on the number of items in the sample and the degree of difficulty of matching stimulus sets differing on a particular independent variable on other stimulus properties. This number was also constrained by the necessity of having stimulus sets that were as largely disparate as possible on the value they had on the independent variable studied. The number of stimulus pairs used was kept as high as possible but could not be made equal for each analysis. The description of these analyses below will indicate the number of stimulus pairs on which each analysis has been conducted.

Results

Tables 1–4 report the main descriptive statistics concerning the analyses examining the effects of word frequency and of relational properties of the stimulus on the rate of neglect errors in EB. Analyses of relational properties have been conducted separately for word and nonword targets. In each table, data is reported in the same format. The first column indicates the independent variable whose effect is analysed. For each independent variable, two sets of items corresponding to the extremes in the distribution of that variable across items (Low/High) were selected and matched pairwise as accurately as possible along a number of other stimulus properties, which are indicated in the caption of each table. In none of the following analyses is there a significant difference between the stimulus sets compared on the properties on which matching was performed (see Appendix). The second and third columns of each table show the average values of the items selected on the independent variable listed on the same row. For instance, in Table 1, the group of low-frequency items that served to study the effect of word frequency had an average frequency of 18.8 occurrences per million. In contrast, the average frequency of the high-frequency words selected was 832.7. The fourth and fifth columns of each table indicate the neglect error rates observed for each level of the independent variable listed on the same row. The last column of each table shows whether the effect of the independent variable studied was significant, and if so, the level of significance.

Word Targets. For word targets, the rate of neglect errors was analysed as a function of word frequency (FREQ; low = 40 or below; high = 200 or higher), number of higher-frequency orthographic neighbours differing from the target on their first letter (N1-HF; low = 0; high = 4 or more), or second letter (N2-HF; low = 0; high = 1 or more[5]), and the number of lower-frequency orthographic neighbours differing from the target on their first (N1-LF; low = 0; high = 4 or more) or second letter (N2-LF; low = 0; high = 1 or more). It can be seen in Table 1 that, of the different stimulus properties analysed, only N1-HF had a large effect on the rate of neglect errors. This observation was confirmed by a chi-square analysis, which showed that an increased number of higher-frequency orthographic neighbours differing from the target on their first letter (N1-HF) increases the probability of a neglect error in EB [$\chi^2(1) = 4.0$; $P < .05$]. In contrast, no effect occurred for FREQ [$\chi^2(1) = 1.0$; n.s.], N2-HF [$\chi^2(1) = 1.1$; n.s.], N1-LF [$\chi^2(1) = 0.8$; n.s.], and N2-LF [$\chi^2(1) = 0.8$; n.s.].

TABLE 1
Summary Statistics for the Analysis of the Effects of FREQ, N1-HF, N2-HF, N1-LF, and N2-LF on the Rate of Neglect Errors to Words

	Independent Variable			*Neglect Errors (%)*		
	Low	*High*	*No. of pairs*	*Low*	*High*	*Effect*
FREQ	18.8	832.7	105	16.2	11.4	*n.s.*
N1-HF	0.0	5.3	100	13.0	24.0	*P* < .05
N2-HF	0.0	1.3	100	23.0	17.0	*n.s.*
N1-LF	0.0	5.1	100	10.0	14.0	*n.s.*
N2-LF	0.0	1.3	100	10.0	14.0	*n.s.*

Word sets used for the study of each independent variable were matched pairwise on every other stimulus property listed in the table as an independent variable. Neglect error rates are reported in percentages as a function of the level (low/high) of each independent variable.

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[5] Four-letter words with several orthographic neighbours differing from them on the second letter are rather rare. To be able to obtain sets of items that were large enough, we were therefore forced to have the high values of N2-HF and N2-LF start at one neighbour instead of four, the value for analyses on N1-HF and N1-LF.

As a follow-up on the effect of N1-HF on the rate of neglect errors shown by EB, a supplementary analysis was conducted to examine whether the average visual similarity between the target and its higher-frequency orthographic neighbours differing from it on their first letter (VS/N1-HF; low = 0.75 or below; high = 3.0 or higher) had any impact on the probability of neglect errors. The descriptive statistics concerning this analysis are reported in Table 2. The results showed a large increase in the rate of neglect errors with an increase in VS/N1-HF [$\chi^2(1) = 5.6$; $P < .02$]. This means that a target with a first letter that is highly similar visually to that of its N1-HF orthographic neighbours is more likely to result in a neglect error in EB than a target that is visually dissimilar to its N1-HF neighbours[6].

Given the effect of visual similarity between the target and its N1-HF neighbours on neglect error rates, one possibility that should be considered is that visual similarity may have contaminated the outcome of our preceding analyses of the effects of FREQ, N1-HF, N1-LF, N2-HF, and N2-LF. Indeed, items compared in these analyses were not deliberately matched on visual similarity. Thus, it could be that the effect of N1-HF emerged as significant only because words with many N1-HF neighbours have a large proportion of

TABLE 2
Summary Statistics for the Analysis of the Effect of VS/N1-HF on the Rate of Neglect Errors to Words

	Independent Variable			*Neglect Errors (%)*		
	Low	*High*	*No. of pairs*	*Low*	*High*	*Effect*
VS/N1-HF	0.5	5.2	100	12.0	25.0	$P < .02$

Low and High VS/N1-HF words were matched pairwise on FREQ, N1-HF, N1-LF, N2-HF, N2LF, VS/N1-LF, VS/N2-HF, and VS/N2-LF. Conventions are as in Table 1.

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[6] An interesting question is whether the visual similarity effect observed here is truly a function of a cohort of items in the N1-HF neighbourhood of the target (VS/N1-HF is an average computed over all N1-HF neighbours) or whether it can be tied to one particular N1-HF neighbour, i.e. that with the greatest visual similarity with the target. This latter alternative was tested by examining the effect of maximum visual similarity between the target and any of its N1-HF neighbours on neglect error rates. One hundred pairs of words for which the maximally similar N1-HF neighbour had a very low (1.5 or below) or very high (4.0 or higher) visual similarity with the target were matched pairwise on N1-HF, N1-LF, N2-HF, N2-LF, the maximum visual similarities of N1-LF, N2-HF, and N2-LF neighbours as well as on FREQ. The results show average neglect error rates of 17% and 24% with targets with low vs. high maximal visual similarity N1-HF neighbours, respectively. This difference is not significant [$\chi^2(1) = 1.5$; n.s.]. What these results suggest is that the effect of visual similarity between the target and its N1-HF neighbours is not a function of a single item in the neighbourhood that would be particularly similar with the target. Rather, the effect appears to originate from a cohort of items made of several (two or more) of the target's N1-HF neighbours.

these neighbours that are highly similar. By contrast, the same rationale may leave doubts concerning the nonsignificant effects of FREQ, N1-LF, N2-HF, and N2-LF. Thus, items with many N1-LF, N2-HF, or N2-LF neighbours may have had only a small proportion of their neighbours differing on the first letter that were highly similar. Similarly, it could be that, by some accident, low FREQ words had rather dissimilar neighbours whereas high FREQ words had highly similar neighbours. Such a mismatch across words from the two FREQ ranges analysed could have prevented any real effect of the variable from emerging. The following additional tests dispel such doubts and validate the outcomes of the analyses presented earlier. The average visual similarity of high N1-HF words with their orthographic neighbours differing from them on the first letter is of 2.13. By comparison, the average visual similarities of neighbours differing on the first letter from words with high numbers of N1-LF, N2-HF, and N2-LF neighbours are of 2.32, 2.38 and 2.09, respectively. None of these latter values differs significantly from that obtained with words with many N1-HF neighbours [all $t(198) \leq 1.1$; n.s.]. Regarding the analysis of FREQ, the average visual similarity of neighbours differing from the target on their first letter was 1.21 for low FREQ words, and 1.58 for high FREQ words, a difference that is not significant [$t(208) = 1.46$; n.s.]. The lower similarity values for the words used in the FREQ analysis compared to those for words used in the various neighbourhood size analyses is explained by the fact that many words in the FREQ analysis had no neighbour differing from them on the first letter, which therefore received a null neighbourhood similarity value.

Nonword Targets. For nonword targets, the rate of neglect errors was analysed as a function of the number of orthographic neighbours differing from the target on their first letter (N1; low = 0; high = 4 or more), or second letter (N2; low = 0; high = 1 or more. Table 3 shows that an increase in the number of orthographic neighbours differing from nonword targets on their first letter (N1) led to a large increase in the probability of a neglect error [$\chi^2(1) = 11.3$; $P < .001$]. In contrast, N2 had no effect on the rate of neglect errors [$\chi^2(1) = 0.75$; n.s.]. The descriptive statistics concerning the analysis of the effect of the

TABLE 3
Summary Statistics for the Analysis of the Effects of N1 and N2 on the Rate of Neglect Errors to Nonwords

	Independent Variable			*Neglect Errors (%)*		
	Low	*High*	*No. of pairs*	*Low*	*High*	*Effect*
N1	0.0	6.4	74	44.6	71.6	$P < .001$
N2	0.0	1.42	74	63.0	57.0	*n.s.*

Nonword sets used for the study of N1 were matched pairwise on N2, and those used for the study of N2 were matched pairwise on N1. Conventions are as in Table 1.

visual similarity between a nonword target and orthographic neighbours differing from it on their first letter (VS/N1; low range = 0.75 or lower; high range = 3.0 or higher) are reported in Table 4. The results show that a change in VS/N1 failed to significantly affect the rate of neglect errors on nonword targets [$\chi^2(1) = 1.5$; n.s.]. It should be noted, however, that although the effect of VS/N1 on nonwords was not significant, high VS/N1 nonwords led to a neglect error rate that was 9.8% higher than low VS/N1 nonwords. This nonsignificant difference is relatively large and rather close to the neglect error rate difference caused by VS/N1-HF with words (13.0%; Table 2), which was significant. Thus, even if the present results suggest an effect of visual similarity of orthographic neighbours that may be asymmetric across words and nonwords, a firm conclusion on this issue seems premature.

Class and Lexicality of Neglect Errors. The analysis of lexicality and class of neglect error reported in the previous section showed that these were not affected by the lexicality of the target in EB. Rather, this analysis indicated a strong covariation between the lexicality of neglect error responses and the class of neglect error committed. Here we show that both class and lexicality of neglect errors are strongly tied to the effects of stimulus relational properties that were found to affect the rate of neglect errors.

Table 5 shows that each of the significant effects of the relational properties of the stimulus on the rate of neglect errors is closely related to the lexicality of the response produced, and that this is true for both word and nonword targets. Thus, as N1-HF, N1, or VS/N1-HF increased, the number of *word* neglect responses increased markedly [all $\chi^2(1) > 5.8$; $P < .02$], whereas little difference occurred on the number of nonword neglect responses [all $\chi^2(1) < 1.0$; n.s.]. In fact, whatever differences are present across the levels of N1-HF, N1, or VS/N1-HF in the number of nonword neglect responses, these are in a direction opposite to the effects of these independent variables on the overall rate of neglect errors (see Table 1, 2, and 3). In other words, the effects of N1-HF, N1, and VS/N1-HF on the rate of neglect errors are linked to changes in the numbers of word neglect responses but show no relation with the rate of nonword neglect responses.

TABLE 4
Summary Statistics for the Analysis of the Effect of VS1/N1 on the Rate of Neglect Errors to Nonwords

	Independent Variable			*Neglect Errors (%)*		
	Low	*High*	*No. of pairs*	*Low*	*High*	*Effect*
VS/N1	0.5	4.7	71	60.6	70.4	*n.s.*

Low and High VS/N1 nonwords were matched pairwise on N1, N2 and VS/N1 nonwords. Conventions are as in Table 1

TABLE 5
Effects of N1-HF, VS/N1-HF, and N1 on the Numbers of Neglect Errors where the Response was a Word or a Nonword (Data is Reported in Numbers of Neglect Errors)

Target Type	*Independent Variable*	*Levels[a] of Indep. Var.*	*Word Neglect Errors*	*Nonword Neglect Errors*
Word	N1-HF	Low	8	5
		High	21	3
Word	VS/N1-HF	Low	7	5
		High	21	4
Nonword	N1	Low	13	20
		High	38	15

[a] Level of independent variable.

Similarly, Table 6 indicates that changes in neglect error rates across levels of N1-HF or VS/N1-HF for words or N1 for nonwords are entirely explained by a change in the number of substitution errors [all $\chi^2(1) > 4.5$; $P < .05$]. Thus, no relation exists between the effects of N1-HF, VS/N1-HF, or N1 and the rates of omission or addition errors [all $\chi^2(1) \leq 1.0$; n.s.].

DISCUSSION

The results reported here have shown that EB suffers from a rather severe case of neglect dyslexia and that her rate of neglect errors is strongly affected by stimulus lexicality. Thus, the symptoms of her neglect dyslexia are much less acute with word than nonword targets (Fig. 1). However, no relation was found between the lexicality of the target and either the lexicality or class of neglect

TABLE 6
Effects of N1-HF, VS/N1-HF, and N1 on the Numbers of Neglect Errors which were Additions, Omissions, or Substitutions (Data is Reported in Numbers of Neglect Errors)

Target Type	*Independent Variable*	*Levels[a] of Indep. Var.*	*Addition Errors*	*Omission Errors*	*Substitution Errors*
Word	N1-HF	Low	2	8	6
		High	2	6	16
Word	VS/N1-HF	Low	2	26	7
		High	2	29	23
Nonword	N1	Low	0	6	6
		High	1	8	18

[a] Level of independent variable.

errors (Figs. 2 and 3). Instead, the latter two variables showed a strong covariation; word responses tended to be associated with substitution errors whereas nonword responses were strongly associated with omission errors. When a neglect error occurred for a target word and the response was also a word, this response tended to have a higher frequency than the target. Congruent with this observation, neglect error rates to words increased when the target had many higher-frequency orthographic neighbours differing from it on their first letter as well as when such neighbours were highly similar visually with the target (Tables 1 and 2). Likewise, neglect error rates to nonwords increased markedly when the target had many neighbours differing from it on their first letter compared to when the item had no such neighbours (Table 3). These orthographic neighbourhood size and visual similarity effects exclusively affected the numbers of neglect errors that were substitutions and where the response was a word; no neighbourhood effect was found on the numbers of omission errors or of nonword responses (Table 5 and 6).

The following discussion is divided in two parts. First, we will examine which of the accounts of the word superiority effect in neglect dyslexia that were presented in the Introduction best explains the observations reported here. Second, we will consider further implications of the present results for our understanding of neglect dyslexia and of the role of attention in reading.

Word Superiority in Neglect Dyslexia

One point that should be underlined first, concerning the reduction of EB's neglect symptoms with words relative to nonwords, is that this effect is unlikely to result from undesirable asymmetries between the properties of these two stimulus sets. Thus, as mentioned in the Methods section, words and nonwords did not differ on single-letter or bigram frequencies, nor on the number of words that can be made if their first letter is omitted or substituted by another letter. This means that the dissociation observed here between words and nonwords cannot be a function of the orthographic regularity of the stimuli, nor of the degree of competition the items would suffer from other words when the subject failed to encode the first letter of the target accurately.

One possible explanation for the reduced symptoms of neglect dyslexia with words is that subjects are more likely to guess the neglected portion of a word than to guess that of a nonwords (Patterson & Wilson, 1990). To apply, this account requires clear evidence for a bias towards producing a word as a response. In the experiment, EB did indeed tend to produce a word more often than a nonword when she committed a neglect error. However, this word bias had a slightly smaller magnitude than that already existing in the stimulus set. Although this may not be entirely decisive, it seems that the applicability of a guessing account would require a word bias that is greater in the responses produced than that present in the stimuli (e.g. Davidson & Tustin, 1978; Green

& Swets, 1966; Macmillan & Creelman, 1991); a condition that is not verified here. Most importantly, despite the fact that the patient was quite aware that the stimuli were all four letters long, the most frequent class of neglect error she produced was that of omissions. This result is incompatible with guessing. That is, if in case of uncertainty EB had tried to guess the item that had been displayed, the minimum criterion that she would have set on her response would have been for it to be four letters long. The present results are incompatible with the application of such a strategy.

Based on the patient's neglect error rate with nonword stimuli (60.3%), the proportion of trials on which strictly bottom-up processes (i.e. not supported by lexical orthographic knowledge) were able to encode the left portion of the stimulus accurately can be estimated at 39.7%. Despite this major difficulty in encoding the beginning of letter strings, stimulus lexicality resulted in a large gain on response accuracy and the evidence suggests this gain cannot be explained by EB using a sophisticated guessing strategy. It therefore appears that the word superiority effect reported here must be attributed to the fact that access to lexical orthographic knowledge did occur despite a partial encoding of the input. Also congruent with the notion of lexical access from partial encoding of the stimulus are the results pertaining to the effects of orthographic neighbours to the target, which are discussed later. Except for the "guessing" account of the word superiority effect in neglect dyslexia, all other explanations of the phenomenon assume that it originates from on-line access to lexical orthographic knowledge. The relative power of these other explanations to account for the current data can be discriminated by considering other aspects of the results.

According to the account of Caramazza and Hillis (1990b), lexical access based on a partial encoding of the input should result in a word superiority effect in neglect dyslexics by virtue of the orthographic regularities existing in the language. One implication of this theory is that, given appropriate assumptions about the orthographic regularities involved and a reasonable estimate of the base rates with which the letter encoding mechanism passed complete vs. incomplete information on letter identities to the system representing lexical orthographic knowledge, it should be possible to predict the probability of correct responses to words. We have conducted this exercise.

The neglect error rate observed with nonwords suggests that letter encoding failed in accurately registering all letters of a 4-letter string on 60.3% of trials (Fig. 1), and that it succeeded in doing so on 39.7% of trials—ignoring, for the sake of simplifying matters, the few mistakes made on the right portion of stimuli. According to Caramazza and Hillis (1990b), these values should remain true when the target is a word since the quality of letter encoding is supposed to be unaffected by target lexicality. To render the present exercise feasible, let us suppose that, on the 60.3% of trials where letter encoding failed, only the leftmost letter of the target was registered inaccurately but all the other letters have been recognised perfectly. This assumption allows us to restrict the domain of possible lexical responses when letter encoding failed to the target and the orthographic neighbours that differ from it on their first letter. For the target words used here, the number of 4-letter words compatible with the last 3 letters of the target is thus limited to an average of 4.3 alternatives (i.e. target plus a mean of 3.3 orthographic neighbours). On the basis of the lexical bias the patient showed in producing a word as a neglect response, it can be assumed that, when uncertain about the identity of the first letter, the patient produced a word as response on 58% of trials. Given these assumptions, a correct response to target words is predicted on 13.5% (58% of lexical responses in case of uncertainty, multiplied by 23.3% [1/4.3] correct choices among the alternatives compatible with the last 3 letters of the target) of the 60.3% of trials where letter encoding failed if the patient had absolutely no information on the first letter of the target. Adding these trials to those whose letter encoding was entirely successful, the predicted overall rate of correct responses to words is of 47.8%, with the remaining 52.2% of trials consisting of neglect errors. This predicted neglect error rate is far above the actual 15.1% observed here with words. The accuracy of the prediction is not greatly helped if we add the further assumption that the word selected for response always had a frequency equal or above that of the target. On average, the words used here had 1.56 higher-frequency orthographic neighbours differing from them on the first letter. Target included, response selection is therefore assumed to have been made over an average of 2.56 items if it is supposed the patient had no information on the first letter of the target. Overall, this leads to a predicted rate of correct responses of 53.4% and thus a neglect error rate of 46.6%. Again, this is well above the observed 15.1% neglect error rate to words. In fact, even if we were to assume that: (1) partial feature information on the first letter was available to the patient when letter encoding failed; (2) that it allowed her to produce the correct response to word targets 100% of the time when she produced a word as response; (3) but that it never permitted any correct response to nonwords—the predicted neglect error rate to words would be 25.3%. Thus, even with assumptions (2) and (3), which are unrealistically biased towards reducing the rate of neglect errors that is predicted for words, the predicted value is still a good deal higher than that observed in EB[7].

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[7] Note that the neglect error rates predicted for word targets by the theory of Caramazza and Hillis (1990b) are exactly the same as those predicted by the guessing account of Patterson and Wilson (1990), because the orthographic constraints that are assumed to affect performance are identical. That these predicted values are higher than those observed in EB therefore add to the previous arguments against an explanation of the lexicality effect on the patient's neglect dyslexia symptoms on the basis of a sophisticated guessing strategy.

From these calculations, it appears that the explanation of Caramazza and Hillis (1990b) fails to predict a reduction in neglect error rate to words relative to nonwords that is as large as that exhibited by the patient studied here. Therefore, it seems that, apart from lexical access based on a partial encoding of the input, some other factor contributed to the low neglect error rate exhibited by EB with words presented as stimuli. Congruent with this notion are results suggested that the patient may have been better able to encode the visual features of the first letter of words than of nonwords. Indeed, as reported in the second part of data analyses, EB's neglect error rate to words was affected not only by the number of N1-HF neighbours (Table 1), but also by the visual similarity between the first letter of the target and that of those N1-HF neighbours (VS/N1-HF effect; Table 2). This visual similarity effect indicates that, on trials when bottom-up letter encoding was not entirely successful, the patient nevertheless managed to register some of the features defining the shape of the first letter of words. This partial representation of the features of the first letter of words helped the patient select the correct response when N1-HF neighbours were highly dissimilar from the target relative to when they were highly similar. By contrast, it is not so clear that partial registration of features of the first letter of the stimulus affected performance with nonword targets. Thus, whereas the number of N1 neighbours did affect the rate of neglect errors to nonwords (Table 3), an increase in the visual similarity of these neighbours (VS/N1) with the target tended to increase neglect error rates, but this effect failed to reach significance (Table 4). It appears then that, when EB failed to identify fully the first letter of nonwords, she may have had less information on the shape of this letter than she had with words, thereby explaining the apparently asymmetric effect of visual similarity across word and nonword targets.

Both the over-prediction of neglect error rates by the account of the word superiority effect of Caramazza & Hillis (1990b), and the apparently asymmetric effect of visual similarity for words and nonwords, suggest that EB's reduced neglect error rate must be explained by a letter-level representation of the stimulus that was improved by target lexicality. Such an improvement is predicted by the hypothesis of facilitatory word-to-letter feedback (Behrmann et al., 1990; McClelland & Rumelhart, 1981; Mozer & Behrmann, 1990; Siéroff et al., 1988) and by the assumption that recognition of stimulus lexicality triggers a realignment of attention to encompass the entire length of the letter string (Brunn & Farah, 1991). As noted previously, however, the latter account states that the lexical status of the target must be recognised before attention may be realigned. This should translate into at least some trend for the responses produced on neglect errors to share the same lexical status as the target. This prediction is not verified since there was no difference in the lexicality of responses produced in cases of neglect errors as a function of whether the target was a word or a nonword (Fig. 2).

From the analysis presented here, it is concluded that EB's reduced neglect error rate with words relative to nonwords is best explained by the hypotheses that access to lexical orthographic knowledge occurred even with partial encoding of the letters constituting the stimulus, and that this lexical access resulted in facilitatory feedback to letter-level representations. By improving the representations the patient achieved of the leftmost (first) letter of words, this feedback caused the neglect error rate to words to be lower than that predicted by the theory of Caramazza and Hillis (1990b), and was responsible for the visual similarity effect, which was found for words but which failed to reach significance for nonwords. The role of word-to-letter feedback in reducing EB's rate of neglect errors with words is congruent with the evidence suggesting that such feedback is also responsible for the word superiority effect in normal readers (McClelland & Rummelhart, 1981).

Neglect Dyslexia Errors and the Role of Attention in Reading

Two additional aspects of the present results are informative with respect to our understanding of the processes leading up to neglect errors in EB and to the levels of processing that may be affected by attention in reading.

In the Results section, a strong tie was noted between the lexicality of the response produced in case of a neglect error, the class of neglect error (omission vs. substitution), and the presence/absence of an effect of orthographic neighbours differing from the target on their first letter. Thus, when a neglect error occurred, word responses tended to be associated with substitution errors whereas nonword responses were closely associated with omission errors. Furthermore, each of the lexical constraints that were found to affect neglect error rates (i.e. effects of orthographic neighbours differing from the target on their first letter; N1-HF, VS/N1-HF, and N1) was exclusively linked to modulations in the rates of word/substitution neglect errors but had no effect over the rates of nonword/omission errors. We suggest these segregated kinds of neglect errors (word/substitution vs. nonword/omission) are a function of distinct ways in which response selection proceeded when the patient failed to encode the leftmost letter(s) of the stimulus.

In the case of word/substitution neglect errors, it is proposed that response selection was based on the set of lexical representations activated by a partial encoding of the stimulus letters. Those activated representations would correspond to words compatible with the portion of the target whose letters are accurately encoded; i.e. the target and other words having their last two or three letters in common with it. Clearly, orthographic neighbours differing from the target on their first letter would be strong contenders under this lexically based response selection process, thereby explaining their effects on the rate of word/substitution neglect errors (N1-HF, VS/N1-HF, N1; Tables 5 and 6). It appears that words with a higher frequency tended to capture the process of response selection among the cohort of activated lexical representations because N1-HF neighbours affected neglect error rates to word targets whereas N1-LF neighbours did not. This response capture by high-frequency words would also explain why, when the target and the neglect response were both words, the response produced tended to be a word with a higher frequency than the target. It should be emphasised that these relative frequency effects are not contradicted by the failure of lexical frequency to affect EB's rate of neglect errors to words (Table 1). That is, the absence of a target frequency effect does not mean that the reading process in EB is entirely insensitive to word frequency. Rather, this result merely implies that low-frequency words are as likely as high-frequency words to cause a significant degree of lexical activation based on a partial letter input. What the relative frequency results (N1-HF effect and target/response relative frequencies) show is that word frequency became determinant for EB's reading accuracy at the stage where one particular lexical representation was selected for response among the lexical cohort that was activated. Finally, the reason why the lexically based response selection process described here was mainly associated with substitution rather than omission errors may be related to the numbers of words of different lengths that were activated by the partial letter input. Thus, the average numbers of three-, four-, and five-letter words (other than the target) which were compatible with the last three letters of the target (word and nonwords combined) used in the present experiment are: 0.16, 3.3, and 1.5, respectively. This means that, across the most likely contenders considered here for a lexically based response selection, four-letter words are by far the highest in number. These words were therefore more likely than words of other lengths to be selected for response, thus resulting in a high rate of neglect substitution errors. Considering how straightforward this explanation is for substitution errors, it appears unlikely that any hypothetical residual capacity of encoding the actual length of the stimulus independent of letter identification abilities has had any role to play in the present results. The degree to which the explanation proposed here for substitution errors in EB applies to other cases of neglect dyslexia (Behrmann et al., 1990; Ellis et al., 1987; Kinsbourne & Warrington, 1962; Patterson & Wilson, 1990; Riddoch et al., 1990; Tegnér and Levander, 1993; Warrington, 1991) who have previously exhibited a clear dominance of substitution errors over other classes of neglect errors is unknown to us. However, it would seem important for future research to investigate the response alternatives that are available when neglect errors are committed when trying to interpret a dominance of substitution errors in neglect dyslexia.

As stated previously, neglect errors separate into two distinct classes, those which are substitutions and where the response produced is a word, vs. those which are omissions and where the response produced is a nonword. It was noted earlier that all lexical constraints that seem to affect neglect error rates in

EB in fact modulate the rate of word/substitution errors but have no effect on the rate of nonword/omission errors. With respect to the latter class of neglect errors, it is proposed that the response produced was based simply on the limited number of letters the patient was able to encode accurately from the stimulus and that no lexical constraints acted on these responses, possibly because the lexical activation produced by the stimulus may have been too weak. In such cases, the omission of the leftmost letter(s) of the stimulus would obviously be the rule. The assumption that the response produced on these trials is not based on any form of lexical activation (i.e. the response is not forced to be a word) would explain why the response produced on a majority of omission errors was a nonword. Indeed, since only the last two or three letters (the latter is the more common observation in the present data set) of the four-letter item presented served as a basis for response, the majority of neglect errors resulting from the response selection process described should be nonwords (cf. low number of three-letter words that can be made from the last three letters of the stimuli used here). The lack of any lexical constraint on this response selection process would also explain why factors related to the orthographic neighbourhood of targets failed to affect the rate of nonword/omission errors.

With respect to the effect of VS/N1-HF on EB's neglect error rate to words, this result suggests that the process involved in letter shape encoding—the feature map or letter shape map in the scheme proposed by Caramazza and Hillis (1990b)—was affected by the attention deficit. Indeed, an increase in neglect error rates with increased visual similarity between the first letter of the target and that of its N1-HF neighbours means that the patient was often unable to encode fully the features defining the shape of the first letter of the target; i.e. only partial feature information was available to her.

A related result obtained in normal observers has been reported by Grainger, O'Regan, Jacobs, and Segui (1992). These authors have measured lexical decision times to words as a function of whether the locus of ocular fixation at stimulus onset is on or off the critical letter disambiguiting the target from a higher-frequency orthographic neighbour. Their results showed that the inhibitory effect of higher-frequency neighbours (e.g. Grainger, 1990) is magnified if the initial ocular fixation is off the critical disambiguating letter. This is explained by the fact that retinal acuity drops off rapidly as one moves away from the locus of ocular fixation. According to Grainger et al. (1992), the reduced visibility of the disambiguating letter in their "fixation-off" condition results in a reduced contrast between the lexical activations for the target and its higher-frequency orthographic neighbour, thus leading to a greater inhibitory effect relative to the "fixation-on" condition. The effect of VS/N1-HF observed here is an analogue of the locus of fixation effect reported by Grainger et al. because both cases concern the quality with which the shape of the letter disambiguating a visual target from its higher-frequency orthographic neighbour(s) is encoded. However, in the Grainger et al. study, shape encoding was modulated by retinal acuity. In the present study, this factor cannot have caused poor encoding of the first letter of the target since this letter was the one closest to ocular fixation—all stimuli were displayed to the right of fixation. Rather, it appears that it is EB's deficit in allocating attention to the leftmost portion of visual stimuli that affected her ability to encode the shape of the first letter of words, thus leading to the VS/N1-HF effect.

To the best of our knowledge, this observation is the first to demonstrate that attention modulates the early visual mechanisms involved in reading that are responsible for letter shape encoding. It should be pointed out, however, that the present results are congruent with previous observations in neglect dyslexia indicating an effect of attention on a retino-centric spatial reference frame. Indeed, according to the theories proposed by Marr (1982; Marr & Nishihara, 1978) and by Caramazza and collaborators (Caramazza & Hillis, 1990b; see also Rapp and Caramazza, 1991), it is within a retino-centric reference frame that shape features are assumed to be represented.

Summary and Conclusions

A patient with left neglect dyslexia, EB, is reported to show less neglect for words than for nonwords. This phenomenon is unlikely to have been caused by word/nonword asymmetries on superficial stimulus properties or by guessing. The lexicality effect on accuracy is best explained by the access to stored lexical orthographic representations from a partial encoding of the letters constituting the stimulus, and by facilitatory feedback to the letter recognition system occurring as a result of this lexical activation. Although lexical access may be responsible for the reduced severity of neglect dyslexia symptoms with word targets, it also seems to determine the occurrence of a substantial proportion of neglect errors as well as their properties. In particular, the results indicate that the competition among lexical contenders that are compatible with the accurately encoded portion of the target tends to favour words with: (1) a high frequency relative to others that are part of this cohort, and (2) a high degree of visual similarity with the target. The latter point supports the hypothesis that spatial attention modulates the effectiveness of low-level operations involved in the encoding of stimulus shape in reading.

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APPENDIX

TABLE A

Statistics on Stimulus Properties on which Matching was Performed across Levels (Low/High) of the Independent Variables Analysed in Table 1

	Independent Variable				*Match Variables*									
					FREQ		*N1-HF*		*N2-LF*		*N1-LF*		*N2-LF*	
	Low	*High*	*No. of pairs*		*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
FREQ	18.8	832.7	105	Av.	–	–	0.6	0.4	0.1	0.1	2.1	2.5	0.5	0.5
				Std. Dev.	–	–	0.9	0.7	0.4	0.3	2.0	2.2	0.8	0.8
N1-HF	0.0	5.3	100	Av.	26.6	15.9	–	–	0.3	0.3	1.1	1.4	0.2	0.2
				Std. Dev.	59.6	25.7	–	–	0.6	0.6	1.5	1.6	0.5	0.5
N2-HF	0.0	1.3	100	Av.	20.6	20.5	1.0	1.0	–	–	0.7	0.7	0.2	0.2
				Std. Dev.	41.0	39.8	1.3	1.3	–	–	1.1	1.1	0.5	0.5
N1-LF	0.0	5.1	100	Av.	200.1	201.6	1.1	1.3	0.3	0.3	–	–	0.5	0.5
				Std. Dev.	527.3	368.8	1.6	1.5	0.5	0.5	–	–	0.7	0.7
N2-LF	0.0	1.3	100	Av.	134.5	134.1	0.6	0.6	0.2	0.2	1.3	1.3	–	–
				Std. Dev.	257.9	255.5	1.0	1.0	0.4	0.4	1.5	1.5	–	–

TABLE B

Statistics on Stimulus Properties on which Matching was Performed across Levels (Low/High) of VS/N1-HF for the Analysis Reported in Table 2

	Independent Variable				*Match Variables*					
					FREQ		*N1-HF*		*N2-LF*	
	Low	*High*	*No.of pairs*		*Low*	*High*	*Low*	*High*	*Low*	*High*
VS/N1-HF	0.5	5.2	100	Av.	70.4	39.3	2.1	3.2	0.5	0.4
				Std. Dev.	177.6	88.3	1.43	1.3	0.8	0.7

					N1-LF		*N2-LF*		*VS/N1-HF*		*VS/N1-LF*		*N2-LF*	
	Low	*High*	*No.of pairs*		*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
VS/N1-HF	0.5	5.2	100	Av	1.8	1.6	0.4	0.3	0.3	0.3	1.1	1.2	0.3	0.3
				Std. Dev.	2.2	1.8	0.7	0.6	0.6	0.6	1.5	1.5	1.1	0.9

TABLE C
Statistics on Stimulus Properties on which Matching was Performed across Levels (Low/High) of the Independent Variables Analysed in Table 3

	Independent Variable				*Match Variables*			
					N1		*N2*	
	Low	*High*	*No. of pairs*		*Low*	*High*	*Low*	*High*
N1	0.0	6.4	74	Av.	–	–	1.1	0.9
				Std. Dev.	–	–	1.2	2.0
N2	0.0	1.42	74	Av	3.3	3.3	–	–
				Std. Dev.	2.9	2.9	–	–

TABLE D
Statistics on Stimulus Properties on which Matching was Performed across Levels (Low/High) of VS/N1-HF for the Analysis Reported in Table 3

	Independent Variable				*Match Variables*					
					N1		*N2*		*VS/N2*	
	Low	*High*	*No. of pairs*		*Low*	*High*	*Low*	*High*	*Low*	*High*
VS/N1	0.5	4.7	71	Av.	2.9	3.5	0.5	0.7	0.5	0.5
				Std. Dev.	2.6	2.2	0.8	1.1	1.5	0.9