SPATIAL AND LINGUISTIC ENCODING OF ORTHOGRAPHIC MATERIAL

Evidence from neglect patients in line bisection tasks

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Ph.D. in Experimental Psychology, Linguistics and Cognitive Neuroscience
XXIV cycle
A.Y. 2011-2012

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Abstract

In line bisection tasks, right-brain damaged patients with unilateral spatial neglect (USN) exhibit a rightward deviation with respect to the objective midpoint of the stimulus, while in neurologically unimpaired participants a reversed bias ("pseudoneglect") has been consistently reported. In a study with healthy subjects, Arduino et al. (2010) suggested the existence of partially independent mechanisms involved in word and line bisection, not only linguistic but also visuo-perceptual. Furthermore, both lexical and syntactic factors are shown to modulate the reading performance in patients with neglect dyslexia (Rusconi et al., 2004; Cubelli & Beschin, 2005; Friedmann et al., 2011).

A series of studies involving USN patients were conducted in order to investigate the spatial and linguistic encoding of orthographic material through a bisection task. In Study I, right-brain damaged patients with USN, right-brain damaged patients without USN, and matched controls were asked to manually bisect words (5-10-13 letters) and lines of comparable length (Exp. 1), and words with final sequences differing on the prediction made concerning how the word should have been read (stressed on the penultimate or antepenultimate syllable; Exp. 2). Study II required the bisection of words and lines of different lengths, radially oriented. In Study III, patients were asked to bisect affirmative and interrogative sentences varying on the syntactic structure, compared to letter strings and lines (Exp. 1), and sentences in which lexical and syntactic alterations were introduced (Exp.2).

Data from Study I demonstrated that most USN patients show a rightward deviation similar for words and lines, with the bias increasing with stimulus length. However, in individual patients USN can affect the bisection of lines and orthographic material with various degrees of severity, demonstrating that at least partially independent mechanisms interact during bisection (Arduino et al., 2010). Furthermore, the ortho-phonological information contained in the final part of a word could act as a cue, modulating the bisection error in patients and healthy subjects. In Study II, radial words are re-oriented during bisection, reaching their canonical orientation. Finally, the linguistic nature of the stimulus induces facilitation in USN patients, who show a reduced error deviation in case of sentences with respect to letter strings and lines (Study III), even when lexical and syntactic alterations were introduced.

In conclusion, visuo-perceptual and linguistic information (both lexical and possibly syntactic) modulates the allocation of attention in word and sentence bisection.

Introduction

Unilateral spatial neglect (USN) is a neuropsychological syndrome, in which patients fail to report sensory events occurring in the side of space contralateral to a brain lesion, and to perform actions in that portion of space. The impairment cannot be explained by primary sensory and motor deficits, which are a frequent consequence of an acquired brain damage, and it can be modality-specific. In some cases, the difficulty can be limited to the left portion of mental images (*representational neglect*; Bisiach & Luzzatti, 1978). Importantly, patients are by and large unaware of the non-attended portion of space (*anosognosia*).

Lesions more frequently involve the right cerebral hemisphere, with USN being referred to the left side of space (Vallar, 1998; Bisiach & Vallar, 2000; Husain, 2008). Brain damage has been traditionally related to focal cortical lesions, as the inferior parietal lobule and the temporo-parietal junction (Vallar & Perani, 1986; Vallar, 2001; Mort, Malhotra, Mannan, Rorden, Pambakian, Kennard, & Husain, 2003), even if recent evidence suggests the involvement of large-scale fronto-parietal networks, in which the role of white matter pathways is stressed (Thiebaut de Schotten, Tomaiuolo, Aiello, Merola, Silvetti, Lecce, Bartolomeo, & Doricchi, 2012; see Bartolomeo, Thiebaut de Schotten, & Chica, 2012, for a recent review; Ciaraffa, Castelli, Parati, Bartolomeo, & Bizzi, 2012, for a case of USN patient with lesions limited to the white matter).

1.1. Line bisection and unilateral spatial neglect

The line bisection task (Schenkenberg, Bradford, & Ajax, 1980) is a clinical test for the detection of USN. The subject is required to manually mark the midpoint of a horizontal line, judging the spatial extent of the stimulus. Right-brain-damaged patients with USN tend to transect the line to the right with respect to the objective midpoint of the stimulus (Bisiach, Capitani, Colombo, & Spinnler, 1976; Heilman, Watson, & Valenstein, 1985; Vallar, Daini, & Antonucci, 2000). Furthermore, the magnitude of the patients' bisection error is modulated by stimulus length, with a larger rightward displacement for longer lines (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983; Marshall & Halligan, 1989). In the study by Bisiach et al. (1983), USN patients were asked to bisect lines varying from 200 mm, 400 mm and 600 mm, exhibiting bisection biases increasing with length. With very short lines (e.g., 25 mm, see Halligan & Marshall, 1988; Tegnér & Levander, 1991) an inversion of the bias could be found, with a leftward error with respect of the objective midpoint of the stimulus (*cross-over effect*, Halligan & Marshall, 1988;

Marshall & Halligan, 1989; Tegnér & Levander, 1991; Chatterjee, 1995; Monaghan & Shillcock, 1998; Doricchi, Guariglia, Figliozzi, Silvetti, Bruno, & Gasparini, 2005; Savazzi, Posteraro, Veronesi, & Mancini, 2007; Binetti, Aiello, Merola, Bruschini, Lecce, Macci, & Doricchi, 2011). Other than stimulus length, the bisection performance in USN patients is also affected by the spatial position of the stimulus. Several studies demonstrated that the rightward bias increases for stimuli placed on the left side of space (Heilman & Valenstein, 1979; Nichelli, Rinaldi, & Cubelli, 1989; Schenkenberg et al., 1980). Finally, the co-presence of visual field defects, as homonymous hemianopia, i.e. loss of vision in the whole hemifield contralateral to lesion side, induces the more marked rightward bisection errors (Daini, Angelelli, Antonucci, Cappa, & Vallar, 2002; Doricchi & Angelelli, 1999; Doricchi, Galati, DeLuca, Nico, & D'Olimpio, 2002; Doricchi, Onida, & Guariglia, 2002). However, line bisection is considered a useful tool to discriminate between USN and visual field defects: patients with pure hemianopia committed opposite bisection errors than patients with USN, and patients with USN and hemianopia (see paragraph *1.2 Line bisection and visual field defects*).

The rightward bias in line bisection task is considered a manifestation of the neglect syndrome, and several accounts have tried to provide explanations of the bisection behavior. It has been proposed that a general distortion of the representation of space can be responsible of the rightward biases in USN patients: the deviation would reflect a truncated or disproportionately compressed perceptual representation of the lateral extent of the line (Bisiach et al., 1983; Bisiach & Vallar, 2000). In a similar theoretical frame, the anisometric hypothesis (Bisiach, Ricci, & Neppi-Modona, 1998; Bisiach, Neppi-Modona, Genero, & Pepi, 1999; Bisiach, Neppi-Modona, & Ricci, 2002; Savazzi et al., 2007) considers the representational space becoming progressively "relaxed" toward the contralesional side and progressively "compressed" toward the ipsilesional one, so that the left half of the line would be perceived as shorter than the right half. Data from the endpoint task and from the line extension task (Bisiach, Rusconi, Peretti, & Vallar, 1994; Bisiach, Pizzamiglio, Nico, & Antonucci, 1996; Chokron, Bernard, & Imbert, 1997) support this view. When patients were presented with a single dot on a paper sheet and asked to reproduce left and right end-points of a previously seen horizontal line, they tend to place the contralesional left end-point disproportionally further in the neglected hemispace and the right end-point disproportionally nearer in the attended hemispace. This would mean that in USN the same distance between two points is represented differently (Bisiach et al., 1996).

Nevertheless, the same pattern of results can be explained not only within a representational frame (Bartolomeo, Urbanski, Chokron, Chainay, Moroni, Sieroff, Belin, & Halligan, 2004). According to the attentional hypothesis (e.g., Kinsbourne, 1993) is spatial attention that could influence the perceptual judgment of horizontal lengths. The overestimation of the right part of a line might be related to a rightward attentional bias and to a directional deficit of disengaging attention (see Bartolomeo & Chokron, 2002, for review). The perceptual salience of the right portion of the line would increase relative to the left portion (Anderson, 1996; Bultitude & Aimola Davies, 2006), yielding the rightward directional error. In the judgment of the spatial extent of a line, the right and the left portion would compete with each other until the point of subjective equality is reached. In left spatial neglect, competition between the left and right portion of the stimulus would be biased, causing the overestimation of the right part (Urbanski & Bartolomeo, 2008, Toba, Cavenagh, & Bartolomeo, 2011). Several studies recorded eye movements when neglect patients bisected lines (Ishiai, Furukawa, & Tsukagoshi, 1989; Ishiai, Sugishita, Mitani, & Ishizawa, 1992; Ishiai, Seki, Koyama, & Gono, 1996; Ishiai, Koyama, Seki, Hayashi, & Izumi, 2006; Barton, Behrmann, & Black, 1998). Ishiai et al. (1989, 1992) reported that patients rarely searched for the left endpoint of a line, fixating a certain point on the right and marking the midpoint without searching to the left.

Finally, motor accounts considered the bisection bias a manifestation of directional motor deficits, such as directional hypokinesia (Heilman & Valenstein, 1979).

Within these theoretical frameworks, the cross-over effect is considered a challenge and several complicated hypothesis has been proposed to explain this effect (see Monaghan & Shillcock, 1998). Some attempts are made in order to give a comprehensive explanation of bisection performance within a representational point of view (Savazzi et al. 2007), while a recent account has stressed the concomitant presence of visual field defects and USN to be necessary for the emergence of the effect (Doricchi et al., 2005; see also Binetti et al., 2011). Nevertheless, the multicomponential manifestations of USN allow for multiple pathological mechanisms, which can include defective attention or loss of the representational medium. More specifically, Corbetta and Schulman (2011) suggest that a more parsimonious explanation of line bisection errors should take into account the processing of the global structure of the stimulus, which could be impaired in at least some USN patients (Delis, Robertson, & Efron, 1986, see also Gallace, Imbornone, & Vallar, 2008).

Finally, some studies demonstrated the dissociation between line bisection and other clinical tests used to measure USN (see Ferber & Karnath, 2001): Karnath and Rorden (2012) consider a deficit in line bisection a manifestation of a profound perceptual disorder, but not one of the core USN symptoms.

1.2. Line bisection and visual field defects

Unilateral lesions to the postchiasmatic visual pathways frequently cause homonymous visual field defects (Zhang, Kedar, Lynn, Newman, & Biousse, 2006), often with an involvement of the extrastriate cortex. Homonymous hemianopia is the most frequent type of field defect, followed by quadranopia and paracentral scotomas. Patients with hemianopia can present visual exploration or scanning deficit, in which saccades are hypometric and spatially disorganized in the blind field (Pambakian, Wooding, Patel, Morland, Kennard, & Mannan, 2000), and reading deficits, known as "hemianopic alexia", due to the parafoveal field loss in absence of alexia (Schuett, Heywood, Kentridge, & Zihl, 2008). Specifically, in a line bisection task they could exhibit a spatial bias towards the blind field, the "hemianopic line bisection error" (Barton & Black, 1998; Barton et al., 1998; Hausmann, Waldie, Allison, & Corballis, 2003; Doricchi et al., 2005; Schuett, Dauner, & Zihl, 2011). When are required to indicate the subjective visual straight ahead direction a similar contralesional deviation is found (Ferber & Karnath, 1999). Recently, Schuett et al. (2011), studying a sample of 129 patients with left- or right-sided unilateral homonymous hemianopia, upper or lower quadranopia, or paracentral scotoma, found the contralesional horizontal bisection error not to be a specific ''hemianopic'' phenomenon, with all patients showed the typical contralesional bias in the bisection task. The origin of the bisection error in hemianopia is subject of debate (see Kerkhoff & Schenk, 2011 for a recent review). Barton and Black (1998) proposed the perceptual disorder together with a strategic shift of attention into the contralesional hemispace to be responsible of the line bisection bias. Supporting this view, eye-movement recordings during line bisection show that fixations are often shifted towards the hemianopic side (Barton et al., 1998; Ishiai et al., 1989). In the same frame, Mitra, Abegg, Viswanathan, and Barton (2010) argue that no extrastriate brain damage is required to produce the bisection error: simulated visual field deficits in healthy subjects correspond in terms of direction and magnitude of the bisection bias to what found in hemianopic patients.

From a different point of view, Zihl, Samann, Schenk, Schuett, and Dauner (2009) suggest that the bisection error should be considered an independent spatial deficit caused by additional damage to extrastriate brain structures, presumably to occipito-temporal areas and the occipital white matter. Recent evidence (Baier, Mueller, Fechir, & Dieterich, 2010) suggested the involvement of the lingual gyrus and cuneus. Manipulations of spatial cueing had no significant effect at all on the bisection error (Kuhn, Rosenthal, Bublak, Grotemeyer, Reinhart, & Kerkhoff, 2012).

In the case of visual-loss hypothesis (Barton et al., 1998; Mitra et al., 2010, see also Schuett, Kentridge, Zihl, & Heywood, 2009), the line bisection bias could be explained by an expansion of subjectively perceived contralesional space. A speculative account could suggest that, the contralesional half of the line, being closer to the fovea, undergoes the well-know cortical magnification of foveal and parafoveal aspects of the retina, and appears bigger (Fuchs, 1922; Teuber, Battersby, & Bender, 1960; Trauzettel-Klosinski, 1997, for the presence of chronic eccentric fixation in patients with hemianopia). However, Kuhn, Bublak, Jobst, Rosenthal, Reinhart, and Kerkhoff (2012) recently observed a null relationship between the capacity to scan the blind field and the hemianopic bisection error.

On the other hand, the spatial-deficit hypothesis (see Zihl et al., 2009) argues only that the bisection error is independent of the visual loss, caused by additional extrastriate brain damage, without specifying the nature of the deficit. One suggestion is that these spatial distortions may depend on the nature of the field defects (see Doricchi, Guariglia, Figliozzi, Silvetti, Bruno, & Gasparini, 2003).

1.3. Neural correlates of line bisection

Within a wide debate concerning the neural basis and brain networks responsible of neglect behavior (Corbetta & Shulmann, 2011; see Bartolomeo et al., 2012, for a recent review), some recent studies tried to identify specific brain area involved in line bisection with respect to other tasks typically used for detecting USN, as cancellation (Binder, Marshall, Lazar, Benjamin, & Mohr, 1992; Rorden, Fruhmann Berger, & Karnath, 2006; Thiebaut de Schotten, Urbanski, Duffau, Volle, Levy, Dubois, & Bartolomeo, 2005). This hypothesis is in line with several dissociations found between types of tasks, as expression of USN signs. In particular, Rorden et al. (2006) proposed that patients who exhibit a pathological performance in line bisection, also show more posterior lesions, than ones in which is cancellation to be impaired: the more dorsal part of the inferior parietal lobule rather the temporo-parietal junction could be considered the best predictor of line bisection errors. On the contrary, impairment in cancellation better correlates with an involvement of the superior temporal cortex and insula. In line with this view, a recent fMRI study with healthy participants (Cicek, Deouell, & Knight, 2009) demonstrated a strong right-hemisphere activation during a line bisection task, with a specific involvement of the intra-parietal sulcus, the lateral peristriate cortex, and the frontal eye field. In a study conducted during brain surgery (Thiebaut de Schotten et al., 2005), two patients were asked to bisect lines while being submitted to the surgical resection of low-grade gliomas. The patients exhibited stronger rightward deviations upon inactivation of the supra-marginal gyrus, i.e. the rostral subdivision of inferior parietal lobule, and of the caudal part of the superior temporal gyrus. Performances were more accurate when more rostral portions of the superior temporal gyrus or the frontal eye field were inactivated.

1.4. Pseudoneglect

For a better comprehension of USN performances in line bisection, it would be important to describe the behavior of healthy subjects, in order to clarify which mechanisms influence the bisection performance in conditions of normality. When asked to manually bisect a line, non-neurological participants exhibited a systematical leftward bias, generally similar across tactile and visual modalities, known as *pseudoneglect* (Bowers & Heilman, 1980; Jewell & McCourt, 2000, for review). The direction of the error is reversed with respect to the bias exhibited by USN patients, and the magnitude of the deviation is much smaller. According to the literature, pseudoneglect has been attributed to an imbalanced hemispheric activation in spatial tasks and to the influence of reading habits, which determines different preferential scanning directions. In particular, the spatial nature of the bisection task would yield a stronger activation of the right hemisphere, specialized for spatial cognition, that would induce an overestimation of the left hemispace and consequently the leftward error deviation in line bisection tasks (Bradshaw, Nettleton, Wilson, & Bradshaw, 1987; Scarisbrick, Tweedy, & Kuslansky, 1987; Tomaiuolo, Voci, Bresci, Cozza, Posteraro, Oliva, & Doricchi, 2010). A recent fMRI study (Cicek et al., 2009) further supports this hypothesis, showing a predominant activation of the right hemisphere specifically in line bisection tasks as an instance of the importance of the right fronto-parietal network in the allocation of attention (e.g., Vallar, 2001).

With regards to scanning direction, Chokron and Imbert (1993), and Chokron, Bartolomeo, Perenin, Helft, and Imbert (1998) reported a significant effect of reading habits in determining leftward or rightward biases with respect to the veridical center of the stimulus: a leftward bisection error was found in French neurologically unimpaired subjects with left-to-right reading scan, and a rightward bias in Israeli subjects with opposite reading habits (right-to-left). Furthermore, in both French and Israeli healthy subjects and right-brain-damaged patients with USN imposed scanning direction determines the direction of the bisection error, irrespective of reading habits. Starting from the left or from the right side induced a leftward or a rightward bias, respectively.

Nevertheless, a lot of other factors influence the bisection performance in healthy subjects (Jewel & McCourt, 2000). The effect of age supports the involvement of the right hemisphere in the task: while young subjects err to the left in line bisection, elderly subjects (i.e., older that 50 years) usually exhibit an reversed rightward deviation, consistent with the hypothesis of a more rapid aging of the right hemisphere coupled with a compensation of the left hemisphere (Dolcos, Rice, & Cabeza, 2002; Schmitz & Peigneux, 2011). Considering handiness, Luh (1995) reported that dextrals erred farther to the left than sinistrals. Other factors modulating pseudoneglect are the task performing hand, line length and scanning direction (i.e., movement direction and visual elaboration of the stimulus): subjects err in the direction from which scanning is initiated (Chokron et al., 1998; Halligan, Manning, & Marshall, 1991).

1.5. Radial line bisection

Compared to the well-known stimulus dimension effect (e.g., length), stimulus orientation has been rarely investigated in bisection performance. When lines are radial-down oriented (i.e., below eye level), normal participants seem to set the midline too farther from the body (up to the midpoint). Several interpretations have been offered for explaining this pattern. Shelton, Bowers, and Heilman (1990) proposed that attention is distributed away from the body during visual activity because vision is mainly deputed to explore far away. Geldmacher and Heilman (1994) suggested that even retinotopic factors have a role in determining the bias. In particular, healthy subjects showed significant differences in mean error position between lines bisected above and below eye level. The mean error was distant to the true center only when the stimuli were below eye level, in which more distant points appear in the upper visual field. Jeerakathil and Kirk (1994) and Toth and Kirk (1996) demonstrated that a further representational bias toward which is considered to be the top of an object, concur to the upward error in radial line bisection. When asked to bisect radial-down lines with the labels “TOP” and “BOTTOM” at the ends, healthy subjects exhibited a bias toward the label “TOP” (Jeerakathil & Kirk, 1994). Alternatively, Chieffi (1996) proposed a geometric illusion effect to be responsible of the upward shift: in asymmetric configurations made up by labels of different lengths, indeed, the subjective midpoint is set toward the smallest stimulus. However, Kashmere and Kirk (1997), using arrowheads as directional cues, induced a bisection bias toward the wider end of the arrowhead in all spatial orientations, and not toward the smallest part as Chieffi (1996) reported, suggesting that multiple factors must contribute to the direction in which normal subjects bisect radial lines.

When lines are made up by characters linearly aligned (letters and symbols), healthy subjects reduce the magnitude of their distal bias compared to radial solid line bisection error (Jeong, Drago, & Heilman, 2006). Jeong et al. (2006) suggested that character-string tasks require more local attention as well as a linguistic processing, increasing the activation of the left hemisphere responsible for a more proximal bias (Weiss, Marshall, Wunderlich, Tellmann, Halligan, Freund, Zilles, & Fink, 2000).

Very few studies have addressed the bisection of radial lines in unilateral brain-damaged USN patients and often with contradictory results. Halligan and Marshall (1991) described a right-hemisphere damage patient with left USN transecting horizontal lines to the right and radial lines too far from the body with respect to the objective midpoint. However, the same authors (Halligan & Marshall, 1993) subsequently reported no relationship between the magnitude of the rightward horizontal displacements and performances on radial bisection: patients exhibiting a significant rightward bias on horizontal bisection can bisect radial stimuli accurately. Furthermore, four out of ten USN patients bisected radial lines too near to the body, and one patient too far from the body with respect to the objective midpoint. Finally, Toth and Kirk (2002) reported USN patients showing inconsistent directional error in the bisection of radial lines, and no representational bias towards the top of the stimulus (induced by verbal cues, arrows and silhouettes), which they conversely found in healthy subjects (Jeerakathil & Kirk, 1994; Toth & Kirk, 1996).

1.6. Neglect dyslexia

Neglect dyslexia is an acquired reading disorder in which patients commit errors in the side of the stimulus contralateral to the side of the lesion (Ellis, Flude, & Young, 1987). When reading a text line, a sentence or a word, they can produce omissions (e.g., *man* instead of *woman),* substitutions (e.g., *fine* instead of *nine*), and much less additions (e.g., *brain* instead of *rain*, see Arduino, Burani, & Vallar, 2002). In western languages, in which reading proceeds from left to right, errors regard the initial part of the orthographic material. The deficit is considered a component of the USN syndrome (Vallar, 1998), and accordingly, patients with neglect dyslexia are typically unaware of their reading disorder (Kinsbourne & Warrington 1962). Nevertheless, neglect dyslexia may occur independent of USN (Costello & Warrington, 1987; Cubelli, Nichelli, Bonito, De Tanti, & Inzaghi, 1991; Bisiach, Meregalli, & Berti, 1990; Behrmann, Black, McKeev, & Barton, 2002, see Vallar, Burani, & Arduino, 2010 for a recent review). Even when visual field deficit are associated, the misreadings are not confined to the part of the word falling in the impaired visual field, suggesting the deficit to be attentional rather than sensory (Kinsbourne & Warrington, 1962). Nevertheless, cases of "hemianopic alexia" reading disorders have been described: in these patients errors, related to the side of the visual field loss, can be due to uncompensated visual field defect and defective oculomotor adaptation (Warrington & Zangwill, 1957).

Neglect dyslexia is classified as "peripheral" dyslexia, affecting the initial stages of reading, both the visual feature analysis of letter strings' components and abstract letter units. Figure 1 represents the levels at which written letter strings processing occur and that could be damaged in neglect dyslexia. These stages precede reading proper: in "central" dyslexias the damage involves any succeeding components of the reading routines.

Types of errors (substitutions, omissions, and additions) vary across patients: different patients may commit more substitutions, more omissions, or both, while addition errors are infrequent (Arduino et al., 2002). Furthermore, as shown for line, the number of errors could increase with stimulus length, i.e., longer letter strings, but no length effect may be also present. In some cases, a substitution error type suggests that the length of the word is encoded, in terms of number of letters maintained in the error (Tegnér & Levander, 1993).

With regards to the anatomical correlations, lesions grossly involve the temporo-parietal-occipital regions (Takeda & Sugishita 1995; Làdavas, Shallice, & Zanella, 1997; Ladavas, Umiltà, & Mapelli, 1997; Arduino et al. 2002; Behrmann et al. 2002; Rusconi, Cappa, Scala, & Meneghello, 2004; Stenneken, van Eimeren, Keller, Jacobs, & Kerkhoff, 2008), sparing more anterior areas. In the study by Lee, Suh, Kim, Seo, Choi, Kim, Chung, Heilman, and Na (2009) including a large group of right-brain damaged patients, neglect dyslexia was associated with more posterior regions than USN patients without reading disorders.

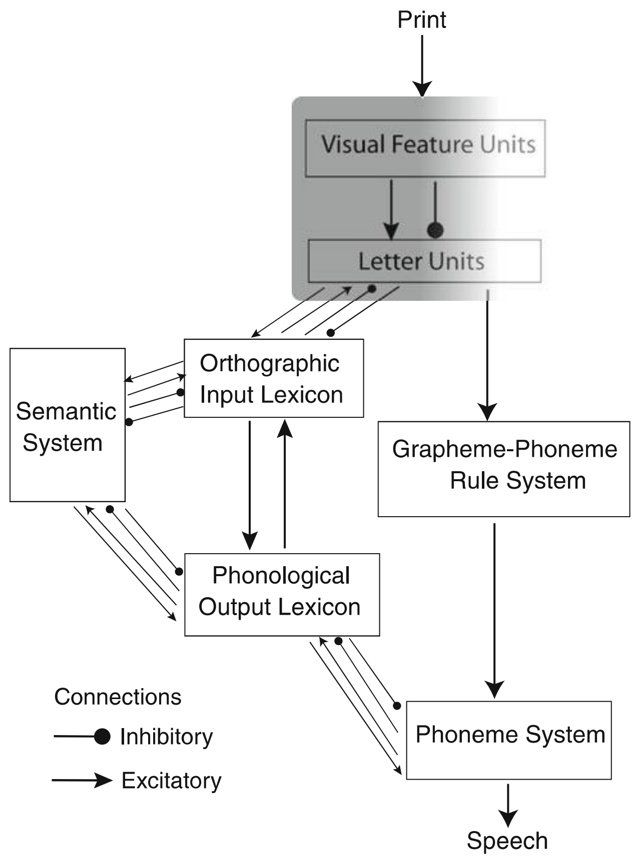

Figure 1. The dual-route cascaded (DRC) model of visual word recognition and reading aloud (by kind permission of Vallar et al., 2010; adapted from Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). The first two stages of processing of written material covering by the grey area are involved in neglect dyslexia.

Neglect dyslexia is a unique opportunity to investigate how linguistic features of the stimulus interact with the allocation of spatial attention. A lot of single-patient and group studies demonstrated that lexical knowledge could influence the attentional deficit (see Vallar et al., 2010). While the lexicality effect involves a better reading of words than nonwords (e.g.. Pagliuca, Arduino, Barca, & Burani, 2008), the lexical effects investigated included word frequency, grammatical class (i.e., nouns read better than verbs and adjectives), orthographic neighborhood or N-size, word concreteness, word regularity, and the presence of morphological constituents. With regards to stress effects, Cubelli and Beschin (2005) demonstrated that the presence of the accent on the last syllable of an Italian word could ameliorate reading performances in patients with neglect dyslexia. This could happen only with real words and not with non-real words, denoting stress as an important cue for lexical access. Furthermore, patients with neglect dyslexia, who fail in reading aloud, could maintain stress location between the target and the paralexic error (Rusconi et al., 2004).

Lexical modulation on the reading performance can be explained by different accounts. It is possible to assume that patients, starting from the correct encoding of the right part of a word, are likely to address its internal representation and to infer the neglected portion of the stimulus (Patterson & Wilson, 1990). Another interpretation, based on the model proposed by McClelland and Rumelhart's (1981), assume that the activation of a lexical representation facilitate low-level letter encoding, through facilitatory feedback (see Behrmann, Moscovitch, Black, & Mozer, 1990; Brunn & Farah, 1991).

Considering the relationship between error type and lexical effects in reading, different pattern of combinations are described, suggesting the existence of discrete mechanisms that could be selectively damaged. Recently, Arduino et al. (2002) suggested that a prevalence of omission errors are indicative of a more severe disorder, comparing to a less severe deficit in which substitutions errors are prevalent.

Nevertheless, the presence/absence of lexical effects indicates different levels of impairment, at which information is unattended early, prior to stimulus identification, or late, after lexical-semantic processing (see Umiltà, 2001, for review). The existence of "lexical" and "non-lexical" neglect-dyslexia types, due to the absence/presence of such lexical effects, is in accordance with a multicomponential account of spatial neglect (Vallar, 1998). However, different models explain the lexical effects starting from a single functional impairment based on different degrees of severity of the deficit (Van der Heijden, Hagenaar, & Bloem, 1984; Pashler & Badgio, 1985; Navon, 1989).

Other than lexical effects, one recent study demonstrated the effects of syntax on sentence reading in Hebrew patients with text-based neglect dyslexia (Friedmann, Tzailer-Gross, & Gvion, 2011). In particular, the syntactic structure was demonstrated to affect the tendency to omit words on the left side, which in Hebrew coincides with the final part of the sentence. The patients studied could shift attention to the left more often when omission of the final constituent would cause ungrammaticality. They committed fewer word omissions in sentences in which the final word was required by syntax, than in sentences that were grammatical even without the final word. Furthermore, optional constituents and pronouns were omitted significantly more often.

As shown for USN, unconscious processing of the stimulus to be read is evident even in neglect dyslexia. This point has been addressed comparing the "explicit" reading aloud, with a lot of "implicit" tasks, such as lexical and semantic decision, which demonstrate some knowledge about the stimulus, without requesting reading (see Vallar et al., 2010). The substantial result emerging from these studies demonstrated a better performance in implicit tasks with respect to read aloud. As discussed above, lexical-semantic processing seems to be largely preserved in neglect dyslexia. This dissociation between explicit and implicit processing in neglect dyslexia can be due to the fact that implicit tasks do not require a sequential phonological processing as reading do.

Furthermore, it is well known that the USN syndrome may occur in two main spatial reference frames (Vallar, 2003): the neglected side can be defined with reference to the patients' body (*egocentric*), or with reference to the object (*allocentric, object-based*), which is independent on the position of the stimulus with respect to the patient's body (Walker, 1995; Halligan, Fink, Marshall, & Vallar, 2003; Vallar, 2003). Similar patterns can be also outlined for neglect dyslexia. In an egocentric, spatial reference frame (*viewer-centred*), the neglected side is defined with reference to the mid-sagittal axis of the patient's body, head, or the fixation point. In this case patients commit errors in the contralesional side of the stimulus, with errors decreasing from the left to right hemifield (see Hillis & Caramazza, 1995; Hillis, Rapp, Benzing, & Caramazza, 1998). Within this pattern of dyslexia, errors are not reported for words vertically oriented, while the increase of the spacing between letters can worsen reading (see Hillis et al. 1998). In an allocentric, object-based reference frame (*stimulus-centred*), the neglected side does not depend on the spatial position of the stimulus with respect to the patient's body. Even in this case vertical reading is preserved (Ellis et al., 1987), and spacing between letters affects the reading performance (Hillis & Caramazza, 1991). Furthermore, mixed patterns of impairment are possible, in which viewer and stimulus-centred errors coexist. In a graphemic reference frame (*word-centred*) errors do not depend neither on the stimulus position with respect to the patient's body, nor on the orientation of the letters, being present even when vertical and mirror-reversed (Caramazza & Hillis, 1990; Hillis & Caramazza, 1990). A recent study with patients with neglect dyslexia (Reinhart, Keller, & Kerkhoff, 2010) demonstrated that passive head rotation to the left can reduce omission errors in the left hemispace, but do not influence word-based errors. This would suggest that text reading can involve two distinct reference frames (Schindler & Kerkhoff, 1997; Behrmann & Tipper, 1999), and that head rotation is likely to affect primarily the global level (space-based) and not the local one (word-based). According to an alternative view, space-and word-based errors are processed by different visual streams, in which the dorsal is more involved in egocentric spatial processing (Hillis, Newhart, Heidler, Barker, Herskovits, & Degaonkar, 2005; Vallar, Lobel, Galati, Berthoz, Pizzamilgio, & Le Bihan, 1999).

1.7. Word bisection

In recent years, the bisection task has been considered a useful paradigm for investigating the spatial representation of written words. Fischer (1996) found that neurologically unimpaired participants show pseudoneglect when bisecting orthographic material, including words, pseudowords (i.e., legal non-words), letter, and symbol strings (Fischer, 2000a). Automatic lexical access may involve an attentional focusing on word beginning (Fischer, 1996, 2000a, 2000b, 2004), in order to establish a cohort of potential entries in the mental lexicon (Paap, Newsome, McDonald, & Schvanveldt, 1982). Consequently, in participants who read from left to right, the extent of the initial part of a word would be over-represented, yielding a systematic leftward error in word bisection (*Attentional Scaling Hypothesis*). In this view, the strong leftward bias showed by Hebrew-English bilinguals with right-to-left reading habits, would reflect a high cognitive involvement during lexical access in their second language (Fischer, 1996). This spatial distortion could be even partially responsible for the leftward bias in the oculomotor behavior during reading tasks. Particularly, O'Regan, Levy-Schoen, Pynte, and Brugaillere (1984) and O'Regan and Jacobs (1992) report an optimal viewing position located just to the left of the middle of the word, that reduces gaze duration, lexical decision time and naming time during word reading. According to Fischer's Attentional Scaling Hypothesis, word bisection bias was induced by high-level cognitive operations related to orthography during readers' automatic attempt to access the meaning of a word, and not to low-level perceptual variables. In collusion with this hypothesis, Fischer (2000a) found no reliable perceptual bias for graphic material, no impact of stimulus dimensionality or segmentation on perceived stimulus center and no influence of word font type (serif/nonserif; proportional/nonproportional) on bisection displacement (Fischer, 2004). The role of attention was investigated with color cues placed on the initial or final part of the word (2000a) and no systematic bias was found related to this type of attentional manipulation. Attentional scaling bias would operate on more abstract word representation and other factors such as number of phonemes in a stimulus may play a role. The presence of a grapheme-phoneme convergence (trigram SCH) leads participants to perceive the string's midpoint closer toward the side with more phonemes. This effect is interpreted as an indication of the automaticity of phonological activation in visual word recognition, although it does not generalize to other weaker grapheme-phoneme convergences (Fischer, 2004). In this view, the attentional scaling hypothesis states that the cognitive representation of a visually presented word is already distorted, due to top-down strategic attention allocation and bottom-up attentional tactics.

More recently, in Italian healthy participants Arduino, Previtali, and Girelli (2010) showed that stimulus length influences the bisection bias for lines and orthographic material differently. Participants asked to bisect words, pseudowords, consonant strings, symbol strings and lines, show definite leftward biases for all types of material with long stimuli, while short stimuli yield opposite biases: still a leftward bias for lines but a rightward bias for orthographic and symbolic stimuli (Figure 2). The authors suggest that not only linguistic, but also visuo-perceptual factors play a role in word bisection, as the difference between discrete (orthographic strings), and continuous (lines) material.

Other studies investigated visuo-spatial elaboration of verbal material through bisection paradigms. Using character and symbol lines, Lee, Kang, Park, Son, Lee, and Adair (2004) reported a systematic rightward error in neurologically unimpaired participants and a stronger rightward displacement in right-brain-damaged patients with USN. Recently, Mohr and Leonards (2007) replicated the rightward displacement showed by Lee et al. (2004): healthy participants were asked to bisect long letter lines in which words were alternately inserted on the right or on the left of the veridical center. Stronger rightward bias was found when words were placed in the left half of the letter line. Furthermore, the manipulation of the meaningful semantic information underlined stronger rightward bisection error for emotional than for neutral words. This asymmetry was explained as a stronger activation of the left hemisphere (Bowers & Heilman, 1980), due to the verbal nature of the task or by a greater demand on local attentional processes, mediated by the left hemisphere (Martin, 1979). Probably, as supposed by Mohr and Leonards (2007), the leftward bias reported in Fischer's studies may be favored by the kind of stimuli used (short letter lines very similar to words), which might have activated word templates and reading strategies.

With regards to USN patients, no studies were conducted on word bisection.

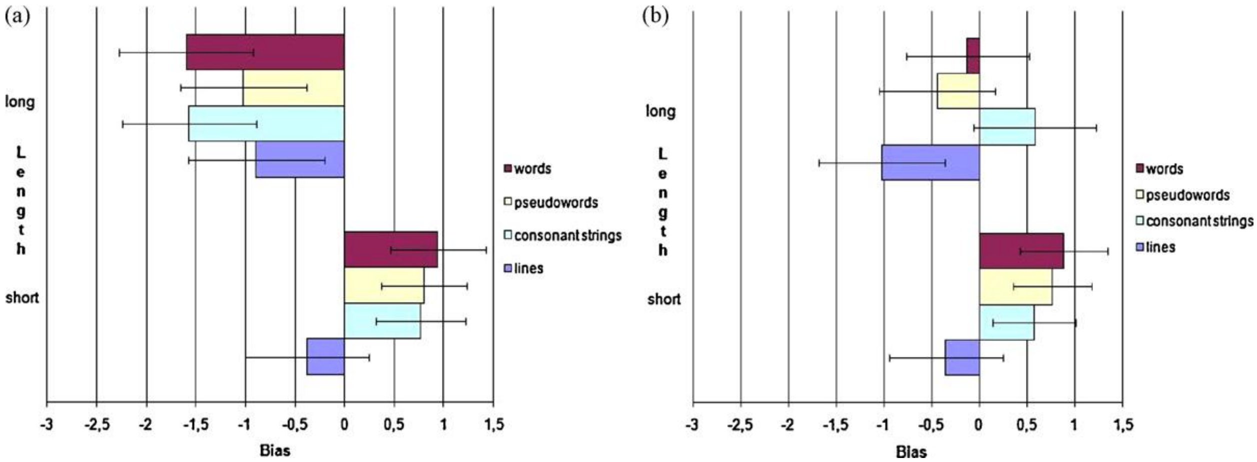

Figure 2. Bisection error in Experiment 1a e 1b (by kind permission of Arduino et al., 2010) as a function of the length of the different types of stimulus.

Experimental part

Three studies were conducted in order to investigate the processing of orthographic stimuli during bisection in USN patients, in order to unveil if and how visuo-perceptual and linguistic features of the stimulus influence the allocation of attention in a length-estimating task. In Study I, a group of right-brain-damaged patients with USN, right-brain-damaged patients without USN and control participants were required to manually bisect words and horizontal lines of different lengths, and words with different stressed-final sequences. The possibility that both visuo-perceptual and lexical features influence the allocation of attention was tested (see Arduino et al., 2010). Study II focused on stimulus orientation, in order to understand how words radially orientated are processed. One possibility is that the horizontal format in which written words are acquired could induce a rotation of the stimulus during bisection, mimicking the typical horizontal pattern of deviations in USN. Finally, participants were asked to bisect and read sentences differing on their syntactic structure, and sentences with lexical and syntactic alterations (Study III). The linguistic processing of the stimulus – from left to right in western languages – could induce a reduction of the typical rightward error exhibited for lines by USN patients (see Friedmann et al., 2011, for the impact of syntax on reading errors in neglect dyslexia).

Finally, results from these three studies are globally discussed in a more general theoretical frame.

2.1. Study I. Bisection of words and lines in unilateral spatial neglect

Due to the few available studies on word bisection, a first aim of the present investigation was to assess whether, in right-brain-damaged patients with left USN, length modulates word bisection in a similar way, in terms of direction and magnitude, extensively documented for lines (e.g., Vallar et al., 2000; Daini et al., 2002). Recently, Arduino, Marinelli, Pasotti, Ferré, and Bottini (2011) reported that, when requested to communicate which letter occupies the central position in visually presented words, USN patients bisect very short words to the left of the veridical center, thus replicating the cross-over effect shown with very short lines (Halligan & Marshall, 1988; Marshall & Halligan, 1989). Similarly, in this study a stronger rightward error for long words than for short ones was predicted. Furthermore, if word and line bisection involves partially independent mechanisms, as suggested for healthy subjects (Arduino et al., 2010), dissociations might be found in the patients' bisection performance of lines and words.

Secondly, the lexical status of the stimulus could influence *per se* the magnitude of the bias. Lexical variables are shown to modulate the reading performance of patients with neglect dyslexia (Vallar et al., 2010, for review). However, in unimpaired participants the results are conflicting. In a word bisection task, both Arduino et al. (2010) and Fischer (1996) found no reliable effects of written frequency on the error deviation in word bisection. The lack of lexical effects may be related to the fact that stimuli were presented with a limited time of exposure, which may have reduced word lexical processing. In this study using an unlimited time of exposure, patients may process the stimuli lexically, thus favoring the emergency of lexical effects (see Arduino, Vallar, & Burani, 2006, for the role of timing in neglect dyslexia's reading errors' pattern). In Italian, word stress is a good candidate to exploit the influence of lexical information in patients with left USN, since the main source of information for setting word stress position is to look at their final (right-sided) part (Burani & Arduino, 2004). In fact, Italian words with three or more syllables have two main stress patterns: they can be stressed on the penultimate (last but one) syllable (e.g., *matìta*, pencil), or on the antepenultimate (last but two) syllable (e.g., *bìbita*, drink). The former is the more frequent stress pattern (dominant or regular), and the latter the less frequent one (non dominant or irregular). Different word final sequences show different proportions of words with dominant or non dominant stress: for instance, most words ending in *–oro* are regularly stressed on the penultimate syllable (about 81%), with only 19% of words taking the irregular stress. The final word sequence could then be used by Italian readers as an informational cue for attributing the correct word stress pattern (Burani & Arduino, 2004; see also Sulpizio, Arduino, Paizi, & Burani, 2012). This may be used as a cue even by neglect patients, modulating the bisection performance. Supporting this hypothesis, other studies show that word stress modulates reading performance both in healthy participants and in patients with left spatial neglect and neglect dyslexia (Cubelli & Beschin, 2005, the presence of an accent mark; Rusconi et al., 2004, with evidence for preserved stress position in the response).

2.1.1. Experiments

2.1.1.1. Participants

Participants were recruited from the inpatient population of the Fondazione S. Lucia IRCCS, Rome (Research Center on Neuropsychology), and from the Casa di Cura Privata del Policlinico, (Department of Neuro-Rehabilitative Sciences), Milan, Italy. A total of 11 right-hemisphere-damaged patients with left spatial neglect (N+), 11 right-hemisphere-damaged patients without left neglect (N-) and 11 unimpaired control participants (C) took part in the study. The N+ patients had suffered a stroke (10 ischemic, 1 ischemic with hemorrhagic infarction). The sample included 4 females and 7 males with a mean age of 67.90 years (SD ±9.25, range 48-79), and a mean education of 9.81 years (SD ±5.19, range 5-18). Mean duration of disease of the 11 patients was 2 months (SD ±1.46, range 1-6). In the N- group, 9 patients had suffered an ischemic stroke and 2 an ischemic stroke with hemorrhagic infarction. The sample included 4 females and 7 males with a mean age of 69.82 years (SD ±9.97, range 44-79), and a mean education of 11.27 (SD ±4.90, range 2-18). Mean duration of the disease was 1.41 months (SD ± .70, range 1-3). The C participants were matched for sex (6 females), age (M age = 68.73, SD ±7.56, range 57-80), and educational level (M education = 10.73 years, SD ±3.90, range 5-17) with the patients. One-way analyses of variance (ANOVAs) showed that age [$F_{(2,30)} = .12$; $p > .05$; $p\eta^2 = .01$], and educational level [$F_{(2,30)} = .27$; $p > .05$; $p\eta^2 = .02$] did not differ among groups (N+, N- and C). Furthermore, duration of the disease did not differ between N+ and N- patients [$t_{20} = 1.21$; $p > .05$]. Lesion site was assessed for each right-brain-damaged patient by CT or MRI scan and drawn manually using the MRIcro software (Rorden & Brett, 2000) onto selected horizontal slices of a standard template brain. Overlapped lesion maps of 21 out of 22 right-brain-damaged patients, subdivided in N+ and N- groups are shown in Figure 3. Scan images were unavailable for N- patient RL, with neuroradiological medical records reporting an ischemic lesion involving the right fronto-temporal areas and the insula. In N+ patients lesions superimposed in the right putamen and in the white matter underneath the insula, the rolandic operculum and the frontal-inferior operculum (11 patients); in N- patients a maximum overlap was observed in the white matter underneath the insula (5 patients). Lesions were more extensive in the N+ (M volume = 105.16 cc, SD ± 73.61) than in the N- group (M volume = 17.31 cc, SD ± 15.37; $t_{11} = 3.87$, $p < .005$), in line with previous findings (Cattaneo, Fantino, Mancini, Mattioli, & Vallar, 2012; Hier, Mondlock, & Caplan, 1983a; Hier, Mondlock, & Caplan 1983b; Leibovitch, Black, Caldwell, Ebert, Ehrlich, & Szalai, 1998).

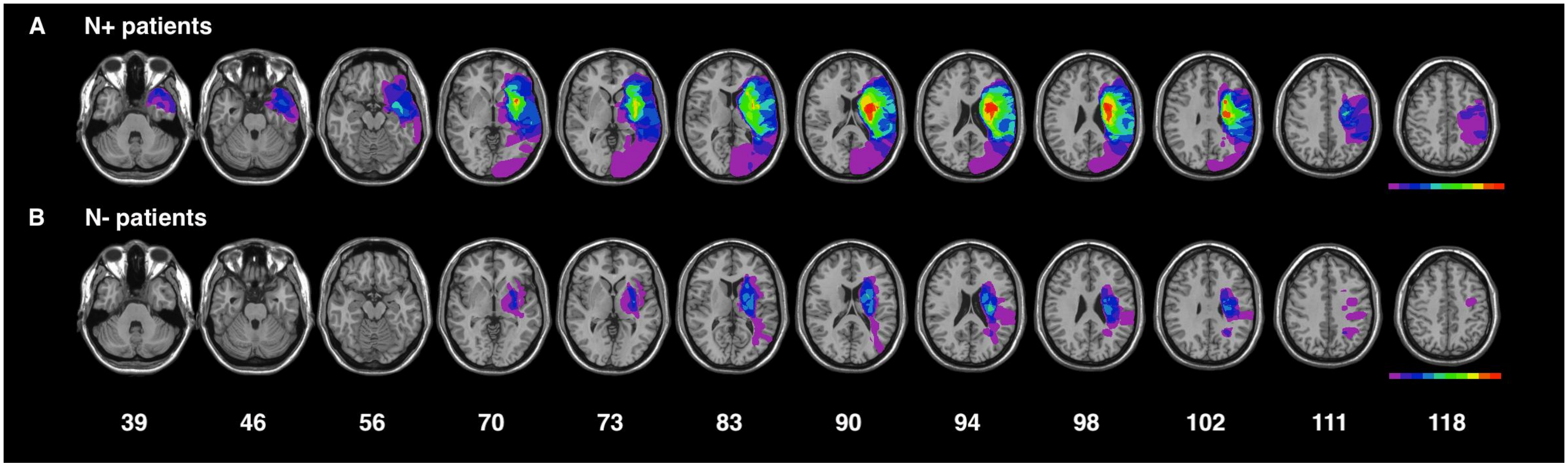

Figure 3. Study I. Superimposition of the right hemispheric lesions in 11 right-brain-damaged N+ patients (A), and in 10 right-brain-damaged N- patients (B). MNI coordinates for the shown axial slices are given. The number of overlapping lesions is illustrated by different colors coding increasing frequencies from violet (n = 1) to red (n = 11). Regions specifically damaged in right brain-damaged N+ patients mainly involved the right putamen and the white matter underneath the insula, the rolandic operculum and the frontal-inferior operculum.

Patients were right-handed on a standard questionnaire (Oldfield, 1971), had normal or corrected-to-normal vision, and no history of previous neurological and psychiatric disorders. All patients but one showed preserved visual fields on Goldmann perimetry or on the confrontation test. N+ patient MA exhibited left hemianopia. All patients were given a Mini Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975) and their scores (N+ M score = 26.53, SD ±1.28, range 25-29; N- M score = 26.76, SD ± 1.91, range 25-30) were above the adjusted cut-off of Magni, Binetti, Bianchetti, Rozzini, & Trabucchi (1996). Demographic and neurological information for N+ and N- patients are shown in Table 1. Informed consent was obtained from all participants, according with the Declaration of Helsinki (British Medical Journal, 302: 1194, 1991).

2.1.1.2. Baseline neuropsychological assessment

The presence and severity of left spatial neglect were assessed by a diagnostic battery, which included the following tests:

a) *Line cancellation* (Albert, 1973). Participants were required to cross out all of the 21 black lines (2.5 cm in length and 1 mm in width), printed on an A3 sheet, 11 in the left-hand-side, and 10 in right-hand-side of the sheet. Neurologically unimpaired participants performed this task without errors.

b) *Letter cancellation* (Diller & Weinberg, 1977). Patients were required to cross out all of 104 H letters printed on an A3 sheet, 53 in the left-hand-side and 51 in the right-hand-side. Targets were presented aligned with other letter distracters. In neurologically unimpaired participants the maximum difference between omission errors on the two sides of the sheet is two (Vallar, Rusconi, Fontana, & Musicco, 1994).

c) *Star cancellation* (Wilson, Cockburn, & Halligan, 1987). The task required to mark out all of the 56 black small stars printed on an A4 sheet, 30 in the left-hand-side and 26 in the right-hand-side. Targets were presented together with distracters (larger stars, letters, and words). In healthy participants one target is the maximum difference between the number of omission errors in the two sides of the sheet (Ronchi, Posteraro, Fortis, Bricolo, & Vallar, 2009).

Table 1. Study I. Demographic and neurological data of 11 right-brain-damaged N+ patients and 11 right-brain-damaged N- patients.

	Sex/Age/Education	Etiology/Lesion Site	Duration of disease (months)
N+ patients			
DF	F/69/8	I/ TFP	1
MV	M/79/5	I/ FT In	2
BA	M/68/5	I/ TF In	1
PF	M/70/17	I/ FTO In	2
LE	F/72/13	I/ P	1
LA	M/74/5	I/ P	1
DMF	M/57/8	I/ FP In ic	1
MP	M/61/8	I/ TFP	2
GP	F/78/5	I/ T In Bg	2.5
MA	M/48/16	I/ PTO	2.5
VI	F/71/8	I H/ TFP	6
N- patients			
DI	F/44/13	I H/ FT In Bg	1
CE	M/78/13	I/ P	1
DA	M/75/13	I/ ic	1
LG	M/67/18	I H/ ic Bg	1.5
RA	M/73/10	I/ P	2.5
VA	M/61/13	I/ t ic	1
RL	M/70/8	I/ FT In	1.5
FA	F/76/2	I/ ec Bg	1
LL	M/73/5	I/ P	3
PG	F/72/11	I/ TP	1
FMT	F/79/18	I/ Bg	1

M/F: male/female; I/H: ischemic/hemorrhagic lesion. F: frontal; P: parietal; T: temporal; O: occipital; In: insula; ic: internal capsule; ec: external capsule; Bg: basal ganglia.

d) *Line bisection*. For line bisection, the patients' task was to mark with a pencil the midpoint of six horizontal black lines (two 10 cm, two 15 cm, and two 25 cm in length, all 2 mm in width), presented in a random-fixed order. Each line was printed in the center of an A4 sheet, aligned with the mid-sagittal plane of the participant's body. The length of the left-hand side of the line (i.e., from the left end of the line to the participant's mark) was measured to the nearest mm. This measure was converted into a standardized score (percentage deviation), namely: measured left half *minus* objective half/objective half *100. This transformation yields positive numbers for marks placed to the right of the physical center, negative numbers for marks placed to the left of it. The mean percentage deviation score of 65 neurologically unimpaired participants, matched for age (M = 72.2, SD ±5.16, range 65-83), and years of education (M = 9.5, SD ±4.48, range 5-18) was -1.21% (SD ±3.48, range -16.2%-+6.2%; Fortis, Maravita, Gallucci, Ronchi, Grassi, Senna, Olgiati, et al., 2010).

e) *Complex figure drawing* (Gainotti, Messerli, & Tissot, 1972). The patients' task was to copy a complex five-element figure: from left to right, two trees, a house, and two pine trees. Each element was scored 2 (flawless copy), 1.5 (partial omission of the left-hand side of an element), 1 (complete omission of the left-hand side of an element), .5 (complete omission of the left-hand side of an element, together with partial omission of the right-hand side of the same element), or 0 (no drawing, or no recognizable element). The total score ranged from 0 to 10. According to normative data from 148 neurologically unimpaired participants (age: range 40-79; education: range 5-13 years of schooling) a score lower than 10 indicated a defective performance (Fortis et al., 2010).

f) *Clock drawing from memory*. Patients were required to draw from memory the hours of a clock in a circular quadrant (diameter 12 cm), printed on an A4 sheet and to indicate the position of the hands requested by the examiner (2.45 PM). The total score ranged from 0 to 10. The normative data reported in Mondini, Mapelli, Vestri, & Bisiacchi (2003) were used.

g) *Sentence reading* (Zoccolotti, Antonucci, Judica, Montenero, Pizzamiglio, & Razzano, 1989). Patients were asked to read aloud six sentences (medium length 8.5 words, 31.8 letters; range 5-11 words, 20-41 letters), printed in uppercase on an A4 sheet horizontally orientated. The score consisted in the number of reading errors (range 0-6). Neurologically unimpaired subjects and right-hemisphere-damaged patients without neglect show no errors in this task.

h) *Single word reading*. Two of the three sets of stimuli of Vallar, Guariglia, Nico, & Tabossi (1996) were used, including two lists of 38 words and 38 orthographically pseudowords, which were obtained from the 38 real words, changing one letter in the left-half of each word, without violating the phonotactic and orthographic constraints of Italian. Stimuli were presented separately in a random-fixed order, with a time-limited computerized procedure. Participants sat about 50 cm away from a 15.4" PC screen in a quiet room, with the center of the screen being aligned with the mid-sagittal plane of the participant's body. E-Prime v 2.0 software was used to display the stimuli. Each trial began with a 300 ms fixation point (a cross, black, 30-pt, Arial font) followed by the appearance of a single word showed in the center of the screen for 500 ms. Letters were presented in black, uppercase, using 37-pt Arial font. The participant's task was to read aloud each letter string, with answers being manually registered by the experimenter. If a participant failed to read correctly all of the first 5 stimuli or 8 out of the first 10 stimuli, time exposure was increased to 750 ms. In case of failure with this time exposure of the stimulus (scored with the same criteria), a 1000 ms exposure was used. No feedback was given as for the participant's accuracy. Pseudoword reading performance is a better predictor for neglect dyslexia, when compared to word reading (Martelli, Arduino, & Daini, 2011). Accordingly, patients were classified as showing left neglect dyslexia when more than 50% of their errors on pseudowords were classified as neglect errors, using the "neglect point" criterion of Ellis et al. (1987): "errors in which target and error words are identical to the right of an identifiable neglect point in each word, but share no letters in common to the left of the neglect point" (loc. cit. p. 445).

A pathological score in at least one test was considered as an index of spatial neglect. Table 2 shows the results of the baseline assessment.

Table 2. Study I. Baseline assessment for left visuo-spatial neglect. Cancellation tasks: number of omissions in the left/right (L/R) hand-side of the display. Sentence reading: number of correct responses. Complex figure drawing: 10/10 indicates errorless performance. Clock drawing: total score ranged from 0 to 10. Line bisection: deviation in mm (-/+leftward/rightward deviation); percentage and number (in brackets) of neglect errors out of the total errors in word and nonword reading. Asterisks indicate defective performance, as compared with normative data.

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N+ patients												
DF	9/11*	0/10*	53/53*	47/51*	5/30*	0/26*	5/6*	3/10*	-6.44	9/10	0 (0/2)	.57* (4/7)
MV	6/11*	0/10*	43/53*	20/51*	30/30*	8/26*	5/6*	4/10*	21.36*	7/10	0 (0/2)	.5 (2/4)
BA	0/11	0/10	33/53*	7/51*	0/30	1/26	1/6*	8/10*	13.36*	3/10*	0 (0/1)	.33 (4/12)
PF	0/11	0/10	6/53*	3/51*	0/30	1/26	0/6	10/10	4.16	7/10	0 (0/1)	.2 (3/15)
LE	8/11*	0/10*	24/53*	16/51*	2/30*	0/26*	1/6*	5/10*	12.51*	9/10	0 (0/2)	.22 (2/9)
LA	0/11	0/10	34/53*	5/51*	n.a.	n.a.	1/6*	4/10*	n.a.	2.5/10*	.17 (1/6)	0 (0/12)
DMF	0/11	0/10	53/53*	31/51*	0/30	0/26	0/6	5/10*	10.5*	2.5/10*	0 (0/0)	0 (0/4)
MP	7/11*	0/10*	39/53*	4/51*	15/30*	2/26*	5/6*	5/10*	-5.18	10/10	1 (1/1)	.5 (1/2)
GP	1/11*	0/10*	53/53*	47/51*	3/30	3/26	2/6*	5/10*	-3.24	1/10*	0 (0/3)	.21 (3/14)
MA	11/11*	1/10*	8/53*	0/51*	10/30	11/26	5/6*	5/10*	16.22*	n.a.	.77* (10/13)	.91* (31/34)
VI	4/11*	0/10*	53/53*	22/51*	30/30*	11/26*	4/6*	6/10*	3.89	3.5/10	0 (0/3)	.29 (4/14)

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N- patients												
DI	0/11	0/10	0/53	0/51	1/30	0/26	0/6	10/10	2.81	9.5/10	0 (0/0)	0 (0/2)
CE	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	4.96	7/10	0 (0/7)	.16 (3/18)
DA	0/11	0/10	0/53	0/51	1/30	0/26	0/6	10/10	5.54	10/10	0 (0/2)	.16 (1/6)
LG	0/11	0/10	0/53	1/53	0/30	0/26	0/6	10/10	-1.93	9.5/10	0 (0/0)	0 (0/0)
RA	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	.99	7/10	0 (0/0)	0 (0/3)
VA	0/11	0/10	1/53	0/51	0/30	0/26	0/6	10/10	2.69	10/10	0 (0/0)	0 (0/1)
RL	0/11	0/10	2/53	3/51	1/30	0/26	0/6	10/10	3.51	9/10	0 (0/0)	0 (0/0)
FA	0/11	0/10	2/53	0/51	0/30	1/26	0/6	10/10	2.26	6/10	.28 (2/7)	.14 (3/22)
LL	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	2.09	8.5/10	0 (0/2)	0 (0/3)
PG	0/11	0/10	0/53	8/51	2/30	3/26	0/6	10/10	3.39	6/10	0 (0/3)	.31 (4/13)
FMT	0/11	0/10	0/53	0/51	0/30	0/26	0/6	n.a.	4.82	6.5/10	0 (0/0)	0 (0/2)

Note: n.a. = not assessed

2.1.1.3. Experiment 1. Bisection of horizontal lines and orthographic strings

In Experiment 1, in order to investigate the influence of both visual and orthographic variables on stimulus bisection, patients with left spatial neglect, right-brain-damaged patients without neglect, and control participants were asked to manually bisect words and lines of different lengths.

2.1.1.3.1. Method

Stimuli and Procedure. Three sets of 20 Italian nouns were selected from a corpus of Italian written language of 3 million tokens (Laudanna, Thornton, Brown, Burani, & Marconi, 1995). Words varied in length (5-10-13 letters), and had a medium word token frequency of 81 (range 5-304). All words were morphological simple, with the dominant (or regular) stress pattern and without double consonants or contextual rules. For 5- and 10-letter words, stimuli were no suffixed nouns, while for 12- or 13-letter words very few suffixed nouns were included, due to the lack of a sufficient number of no-suffixed Italian words matched for length. All 3 categories of stimuli were approximately matched for number and position (initial vs. final) of ascending and descending letters (see Appendix A).

Each word was printed in lowercase, 54-pt, Arial font: 5-letter words had a medium length of 44.6 mm (SD ±5.6, range 34-55), 10-letter words of 88.2 mm (SD ±6.9; range 75-100), and 13-letter words of 104.4 mm (SD ±7.9; range 94-126). The distance between the leftward extremity of the first letter and the rightward extremity of the last letter was measured to the nearest mm[1]. A total of 60 lines (2-pt in width) matched one by one for length (in mm) with the words were designed. Stimuli, both words and lines, were presented in the center of an A4 sheet horizontally oriented, each page containing four stimuli located one above the other, with the center of the sheet being aligned with the mid-sagittal plane of the participant's body at a viewing distance of about 40 cm. A moveable window was used in order to present each stimulus one at a time. Participants were free to move their head and eyes throughout the task.

Words and lines were divided into two parts, in which the three types of length were equally represented. An ABBA order (words-lines-lines-words) was used for half of the patients and a BAAB (lines-words-words-lines) for the other half. The experiment was performed in a single session. Patients were individually tested in a quiet room, with the experimenter sitting in front

[1] In the case of words starting with the letters "t" and "f", the measure began from the vertical bar rather than the horizontal one.

of them. The patients' task was to bisect each stimulus, marking the mid-point with a pencil using the unaffected ipsilesional right hand. Participants were informed that the bisection mark could be made in any point of the word, irrespective of whether it might fall between two letters or go through a letter. No time limits were imposed, but participants were instructed not to count letters. No feedback was given with respect to the accuracy of the response. The distance between the left end of each stimulus and the participant's mark was measured to the nearest mm. Each measure in mm was converted into a standardized score (measured left half *minus* objective half/ objective half *100), in order to equate the participants' error with respect to stimulus length. This percent deviation yielded positive values for rightward deviations with respect to the objective midpoint of the line, negative values for leftward deviations (Rode, Michel, Rossetti, Boisson, & Vallar, 2006).

Statistical analyses. Average standardized scores were analyzed by repeated-measures ANOVAs with two within-subjects factors (type of stimulus and length), and one between-subjects factor (the groups of participants). In order to control for a possible effect of lesion size in determining the different bisection pattern in N+ and N- patients, an analysis of covariance (ANCOVA) on the patients' mean deviations was carried out, with group (N+, N-) as the between-subjects factor, and type of stimulus and length as the within-subjects factors, and lesion size as the covariate (mean-centered prior to the analysis). The Greenhouse-Geisser correction for repeated-measured analyses (Greenhouse & Geisser, 1959) was used, in order to correct for violations of the sphericity assumption whenever necessary. For every analysis, we calculated the partial Eta Squared ($p\eta^2$), which measures the proportion of the total variance that is attributable to a main factor or to an interaction (Cohen, 1973), and whenever necessary pairwise comparisons were performed with Student-Newman-Keuls' post-hoc multiple comparisons. The level of significance was always set at $p < .05$. Subsequently, to assess for any significant defective performance with different types of stimuli in individual patients with left spatial neglect, we compared the average deviations errors of each patient in the word and line test with the means of healthy participants. The analyses were performed by t-tests following the procedure of Crawford and Garthwaite (2002), testing whether an individual's score was significantly different from a mean control sample. Using the Revised Standardized Different Test (Crawford & Garthwaite, 2005), we also tested whether the difference between an individual's standardized scores on word and line bisection was significantly different from the mean differences observed in a control sample.

2.1.1.3.2. Results

Figure 4 shows the percent error made by the three groups (N+, N- and C participants) for the two types of stimuli, and lengths. N+ patients made a larger average bisection error than both N- and C participants, with a rightward bias increasing with stimulus length. N- patients exhibited a rightward deviation with all kinds of stimuli, greater for lines than for words, with the error increasing with length only in the case of lines. Control participants were overall quite accurate. They showed a leftward bias for long words and a rightward bias for long lines, while they were quite accurate with short stimuli.

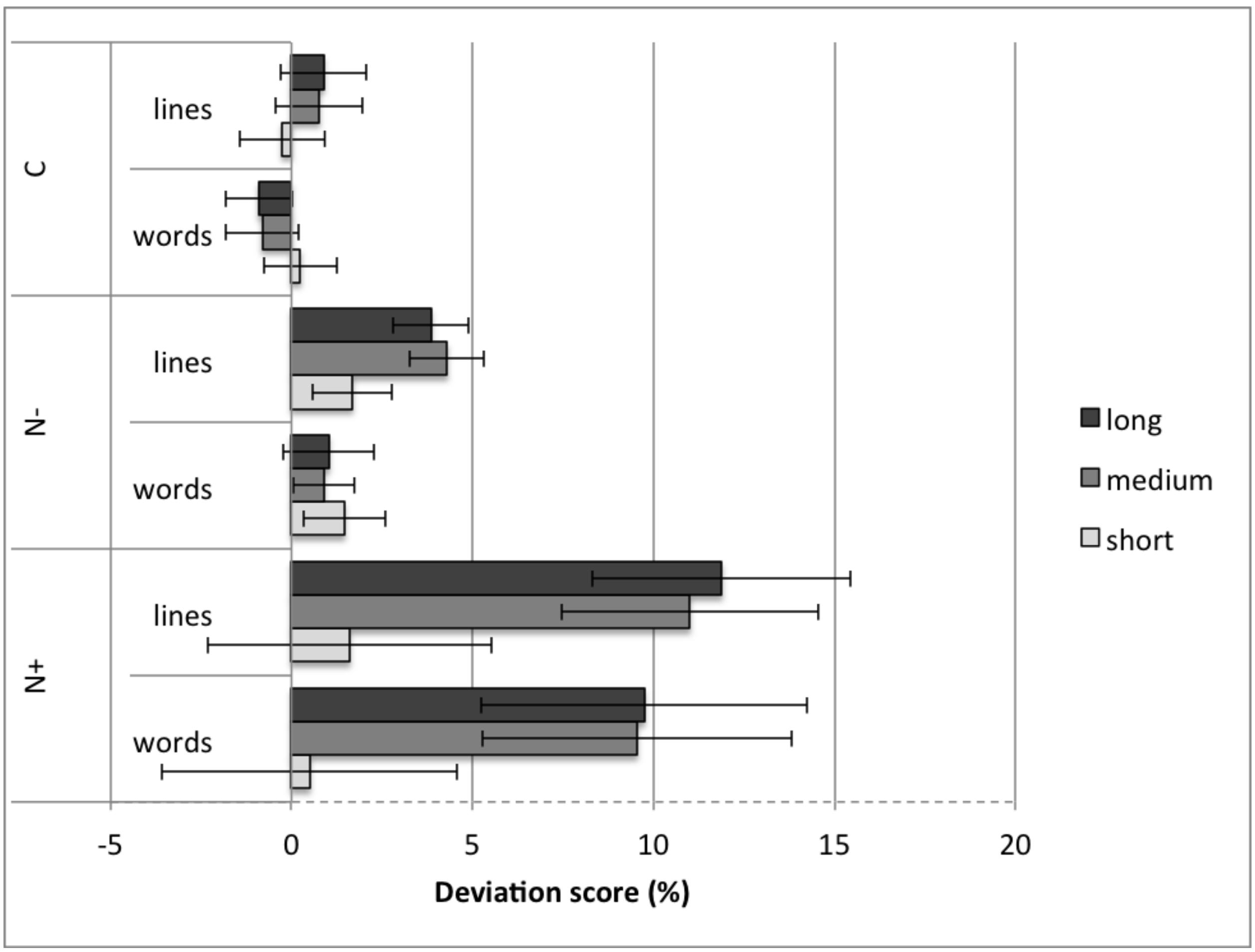

Figure 4. Study I, Experiment 1. Mean percent deviation error (±SE) by group [11 N+ patients, 11 N- patients, and 11 control participants (C)], stimulus type (words and lines), and stimulus length (short: white column; medium: light grey column; long: dark grey column; lines had the same length in mm: short, medium, and long).

The ANOVA revealed significant main effects of group (N+ patients, N- patients and control participants) [$F_{(2,30)}$= 4.19; p< .05; pη² = .22], and of length (short, 5 letters; medium, 10 letters; and long, 13 letters) [$F_{(1,32)}$ = 8.99; p< .005; pη² = .23], while the main effect of type of stimulus (words vs. lines) was not significant [$F_{(1,30)}$ = 1.12; p> .05; pη² = .04]. The type of stimulus by group [$F_{(2,30)}$ = .06; p> .05; pη² = .004], and the type of stimulus by length by group [$F_{(3,60)}$ = .58; p> .05; pη² = .04] interactions were not significant. The length by group [$F_{(2,32)}$ = 6.80; p< .005; pη² = .31], and the type of stimulus by length [$F_{(2,48)}$ = 4.10; p< .05; pη² = .12] interactions were significant. *Post hoc* multiple comparisons revealed that N+ patients exhibited significant differences in bisecting short (deviation M = 1.05%) and medium and long stimuli (M = 10.27%, and 10.81%, respectively; p< .001 for both comparisons), while medium and long stimuli did not differ each other (p> .05). In the N- groups, differences between short (M = 1.57%), medium (M = 2.60%), and long stimuli (M = 2.44%) were not significant (p> .05 for all comparisons). Similarly, no differences were found between lengths in the C group (short M = -.005%, medium M = -.02%, long M = -.01%; p> .05 for all comparisons). Furthermore, deviations made by N+ patients with medium and long stimuli differed from the biases exhibited by N- and C participants with all type of lengths (p< .05 for all comparisons); conversely, no differences were found for short stimuli (p> .05, for all comparisons). No significant differences were found between lengths when comparing N- and C groups (p> .05, for all comparisons). As for the type of stimulus by length interaction, short words (M = .74%) differed from medium and long words (M = 3.21%, and M = 3.29%, respectively, p< .001 for both comparisons), while medium and long words did not differ each other (p> .05). Similarly, short lines (M = 1.01%) differed from medium and long lines (M = 5.35%, and M = 5.54%, respectively, p< .001 for both comparisons), and no differences were found between medium and long lines (p> .05). Furthermore, short words did not differ from short lines (p> .05), while they were significantly different from medium and long lines (p< .001, for all comparisons). Medium and long words were significantly different from the lines of all lengths (p< .001 for all comparisons).

Given the significance of the group by length interaction, the participants' performances were further analyzed by three repeated-measures ANOVAs, in N+ patients, N- patients and healthy controls, with type of stimulus (words vs. lines) and length (small, 5 letters; medium, 10 letters; and long, 13 letters) as within-subjects factors. In the N+ group, the main effect of type of stimulus [$F_{(1,10)}$ = .14; p> .05; pη² = .01], and the type of stimulus by length interaction [$F_{(2,20)}$ = .14; p> .05; pη² = .01] were not significant. The main effect of length [$F_{(1,10)}$ = 8.43; p< .05; pη² =

.46] was significant. *Post hoc* multiple comparisons revealed a significant difference between short and medium stimuli (M = 1.05% vs. M=10.27%; $p< .005$), and between short and long stimuli (M = 1.05% vs. M = 10.81%; $p< .005$), while there was no difference between medium and long stimuli (M = 10.27% vs. M = 10.81%; $p> .05$). In the N- patients group, the ANOVA revealed a significant main effect of type of stimulus [$F_{(1,10)} = 6.12$; $p< .05$; pη² = .38], while the main effect of length [$F_{(2,20)} = .91$; $p> .05$; pη² = .08] failed to reach significance. The interaction type of stimulus by length was significant [$F_{(2,20)} = 6.69$; $p< .01$; pη² = .40]. *Post hoc* multiple comparisons revealed a “length effect” only in the case of lines: significant difference were found between short and medium lines (M = 1.68% vs. M = 4.30%; $p< .01$), and between short and long lines (M = 1.68% vs. M = 3.85%; $p< .01$), and no difference between medium and long lines (M = 4.30% vs. M = 3.85%; $p> .05$). No significant differences were found between words of different lengths (short, medium and long, M = 1.46%, .89%, 1.03%, respectively, $p> .5$ for all comparisons). Short lines were not different from words of all lengths ($p> .05$ for all comparisons), while medium and long lines were different from words of all lengths ($p< .01$ for all comparisons). In the control group, the main effects of type of stimulus [$F_{(1,10)} = .98$; $p> .05$, pη² = .09] and of length [$F_{(2,20)} = .001$; $p> .05$, pη² = .00] were not significant. The type by length interaction was significant [$F_{(2,20)} = 5.60$; $p< .05$; pη² = .36]. *Post hoc* multiple comparisons revealed significant differences between medium words and medium lines (M = -.81% vs. M = .76%; $p< .05$), medium words and long lines (M = -.81% vs. M = .88%; $p< .05$), long words and medium lines (M = -.90% vs. M = .76%; $p< .05$), and long words and long lines (M = -.90% vs. M = .88%; $p< .05$ for both comparisons). No differences were found between medium words and short lines (M = -.81% vs. M = -.25%, $p> .05$), long words and short lines (M = -.90% vs. M = -.25%, $p> .05$), and short words and lines of all lengths (M = .25% vs. M = -.25%, .76%, .88%, respectively; $p> .05$ for all comparisons). Furthermore, there were no significant differences between short and medium words (M = .25% vs. M = -.81%; $p> .05$), short and long words (M = .25% vs. M = -.90%; $p> .05$), medium and long words (M = -.81% vs. M = -.90%; $p> .05$) and between short and medium lines (M = -.25% vs. M = .76%; $p> .05$), short and long lines (M = -.25% vs. M = .88%; $p> .05$) and medium and long lines (M = .76% vs. M = .88%; $p> .05$).

The ANCOVA revealed a significant main effect of the covariate lesion size [$F_{(1,18)} = 10.96$; $p< .005$; pη² = .38]. Importantly, the main effect of group [$F_{(1,18)} = 5.13$; $p< .05$; pη² = .22], and the main effect of length [$F_{(1,19)} = 9.03$; $p< .01$; pη² = .33] were significant. The main effect of type of stimulus [$F_{(1,18)} = .70$; $p> .05$; pη² = .04] was not significant. The length by group interaction was significant [$F_{(2,36)} = 5.25$; $p< .01$; $p\eta^2 = .23$], while all the other interactions failed to reach the significance level: type of stimulus by length [$F_{(2,36)} = 1.80$; $p> .05$; $p\eta^2 = .09$], type of stimulus by group [$F_{(1,18)} = .02$; $p> .05$; $p\eta^2 = .001$], type of stimulus by lesion size [$F_{(1,18)} = 1.18$; $p> .05$; $p\eta^2 = .06$], length by lesion size [$F_{(2,36)} = .93$; $p> .05$; $p\eta^2 = .05$], type of stimulus by length by group [$F_{(2,36)} = .82$; $p> .05$; $p\eta^2 = .04$], and type of stimulus by length by lesion size [$F_{(2,36)} = .69$; $p> .05$; $p\eta^2 = .04$].

The performances of the individual N+ patients were compared with those of control participants for long stimuli, since the above reported ANOVAs showed no differences between N+ and control participants for short stimuli and between medium and long stimuli in the N+ group (see Figure 5). When individually compared to the control group, all but one patients (DMF: words = +4.66% of deviation error, $t_{(10)} = 1.73$, $p> .05$; lines = +5.08%, $t_{(10)} = 1.03$, $p> .05$) exhibited some degrees of difference in the amount of error in one or both bisection conditions. In particular, six patients had a significantly defective performance for both words and lines with respect to healthy controls (MV: words = +9.46%, $t_{(10)} = 3.23$, $p< .01$; lines = +42.31%, $t_{(10)} = 10.14$, $p< .0001$; PF: words = +10.86%, $t_{(10)} = 3.67$, $p< .01$; lines = +9.48%, $t_{(10)} = 2.11$, $p< .05$; LE: words = +10.13%, $t_{(10)} = 3.44$, $p< .01$; lines = +8.82%, $t_{(10)} = 1.94$, $p< .05$; MP: words = +27.94%, $t_{(10)} = 8.99$, $p< .0001$; lines = +14.70%, $t_{(10)} = 3.38$, $p< .01$; MA: words = +28.95%, $t_{(10)} = 9.31$, $p< .0001$; lines = +20.43%, $t_{(10)} = 4.79$, $p< .001$; VI: words = +11.15%, $t_{(10)} = 3.76$, $p< .01$; lines = +14.81%, $t_{(10)} = 3.41$, $p< .01$). Three patients exhibited defective performances for words only (DF: words = +6.01%, $t_{(10)} = 2.15$, $p< .05$; lines = -2.11%, $t_{(10)} = -.73$, $p> .05$; LA: words = +8.52%, $t_{(10)} = 2.94$, $p< .01$; lines = +7.72%, $t_{(10)} = 1.67$, $p> .05$; GP: words = +17.48%, $t_{(10)} = 5.73$, $p< .0001$; lines = +6.44%, $t_{(10)} = 1.36$, $p> .05$). Patient BA showed a significantly leftward bias for words (-27.97%, $t_{(10)} = -8.44$, $p< .0001$), while he was quite accurate with lines (+3.04%, $t_{(10)} = .53$, $p> .05$).

Comparing the difference between word and line bisection in the individual patient with the same average difference in the control group, five out of 11 patients showed no significant differences (PF: $t_{(10)} = 1.54$, $p> .05$; LE: $t_{(10)} = 1.48$, $p> .05$; LA: $t_{(10)} = 1.25$, $p> .05$; DMF: $t_{(10)} = .70$, $p> .05$; VI: $t_{(10)} = .34$, $p> .05$). Patient MV bisected lines more rightwards than words ($t_{(10)} = 6.26$, $p< .001$), three patients out of 11 exhibited larger rightward displacements for words than for lines (MP: $t_{(10)} = 5.21$, $p< .001$; MA: $t_{(10)} = 4.29$, $p< .005$; GP: $t_{(10)} = 4.16$, $p< .005$). Patient BA showed a strong leftward deviation only with words, being accurate with lines ($t_{(10)} = 7.77$, $p< .001$). Patient DF bisected lines leftwards and words rightwards ($t_{(10)} = 2.81$, $p< .05$).

In sum, data from single-patient analyses suggest that left spatial neglect affects in a differential fashion the bisection of words and lines.

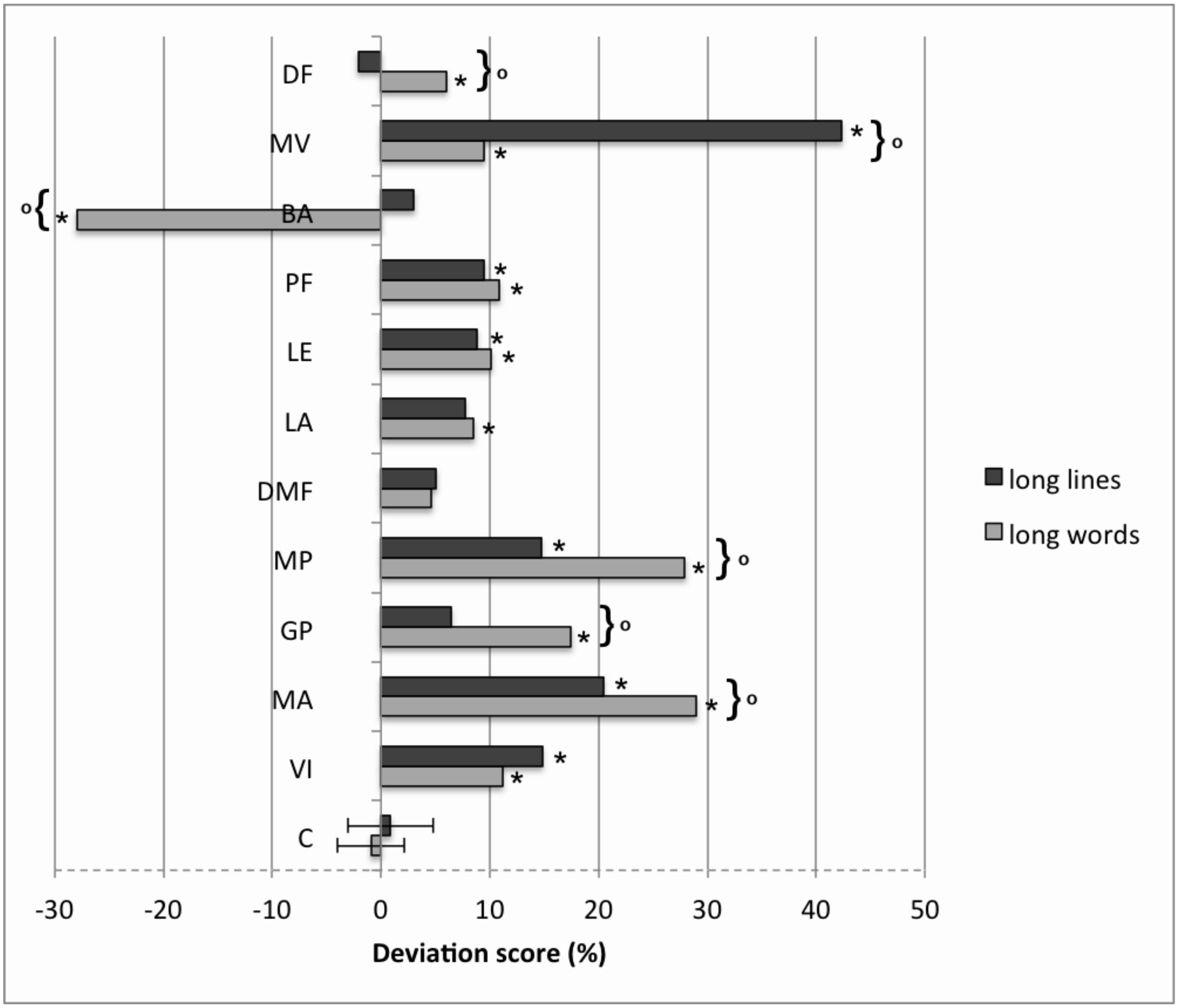

Figure 5. Study I, Experiment 1. Mean percent deviation error by stimulus type (words and lines), of each of the 11 N+ patients. The mean error (±SE) of the 11 C participants is shown in the bottom row. Asterisks: significant difference between each patient's score and the mean score of the C group for each stimulus condition. Circle and brackets: significant difference between word and line bisection in the individual patient, compared to the average difference in the C group.

2.1.1.4. Experiment 2. Word stress and word bisection

In Experiment 2, the effects of stress on word bisection were investigated. Italian words with three or more syllables have two main stress patterns: they can be stressed on the penultimate (last but one) syllable (e.g., *matìta*, pencil), or on the antepenultimate (last but two) syllable (e.g., *bìbita*, drink). Importantly, in both cases, stress is not marked in the written form, and it cannot be derived by rules. One of the two stress patterns is however much more frequent than the other. According to various estimates (see, e.g., Thornton, Jacobini, & Burani, 1997), the proportion of Italian words with stress on the penultimate syllable is much higher (about 80%) than the proportion of words stressed on the antepenultimate syllable (18%, approximately). Thus, words with the more frequent or dominant stress are considered to be "regular", and words with less frequent or non dominant stress to be "irregular" words.

In addition, to stress regularity or dominance, a second characteristic of the distribution of Italian stress pattern governs stress assignment to Italian polysyllables. The occurrence of stress on either the penultimate or on the antepenultimate syllable is related to the word final sequence of phonemes (i.e., the "nucleus" of the penultimate plus the final syllable). Different word final sequences show different proportions of words with dominant or non dominant stress. For instance, while most words ending in *-oro* are regularly stressed on the penultimate syllable (about 81%), with only 19% of words taking the irregular stress, most words ending in *-ola* take the irregular stress on the antepenultimate syllable (about 77%), with only a 23% of words taking the regular stress. This stress distribution results in the following possible cases: regular stress words with many stress "friends", regular stress words with many stress "enemies"; irregular stress words with many stress "friends" and irregular stress words with many stress "enemies". By taking the same final sequence we may have regular and irregular stressed words differing in having stress friends or stress enemies. So, for example, the regular stressed word "castòro" (beaver) has many stress friends, in that the vast majority of words ending in *–oro* are regularly stressed on the penultimate syllable, while the irregularly stressed word "fòsforo" (phosphorus) could be defined as having many enemies. Burani and Arduino (2004) in unimpaired adult participants found an effect of stress neighborhood: words were read aloud faster and more accurately when they had a prevalence of stress "friends", irrespective of stress regularity. This result clearly indicates that the final word sequence can be used as an informational cue for attributing the correct word stress pattern. Accordingly, patients with left neglect, who typically attend the right hand-side of a word more than the left-hand side, would manifest this influence possibly even strongly. The rightward final sequence, which indicates the probability to have a word stressed on the penultimate or the antepenultimate syllable, could modulate the bisection bias. In particular, guessing that the word is likely to be irregular, patients could orient towards the initial (left-sided) part of the word, thus reducing the rightward, neglect-related, bias. To this aim, both patients and controls were asked to manually bisect words with different final sequences, which, as discussed earlier, can be used as orthographic cues for predicting word stress.

2.1.1.4.1. Method

Stimuli and Procedure. The stimuli of Burani and Arduino (2004) were used. Stimuli were divided into two lists, according to the type of final sequences: i) 30 words containing final sequences as -*oro*, which characterized more regularly stressed words (penultimate final sequence words); ii) 30 words containing final sequences as -*ola*, which characterized more irregularly stressed words (antepenultimate final sequence words). Stimuli are reported in Appendix A. Words were 6 to 9 letter long, and were of low frequency (Istituto di Linguistica Computazionale, 1989). As in Experiment 1, each word was printed in lowercase, 54-pt, Arial font: penultimate final sequence words had a mean length of 55.2 mm (SD ±9.49, range 41-76), antepenultimate final sequence words had a mean length of 55.2 mm (SD ±10.57, range 42-73). Procedures and scoring modality were identical to those of Experiment 1.

Statistical analyses. The data were analyzed by repeated-measures ANOVAs with a within-subjects factor (type of stimulus), and one between-subjects factor (the three groups of participants). The performances of the individual patients were analyzed as in Experiment 1.

2.1.1.4.2. Results

As shown in Figure 6, N+ patients made a larger average bisection error than N- patients and neurologically unimpaired participants in word bisection. In the patients' group the error was towards the right side in both conditions, with a greater rightward bias for the penultimate final sequence words, as compared to the antepenultimate ones. N- patients and unimpaired participants exhibited a similar pattern, although less pronounced.

The ANOVA revealed a significant main effect of the type of stimulus [$F_{(1,30)}$= 5.91; p< .05; $p\eta^2$ = .16], while the main effect of group [$F_{(2,30)}$ = .40; p> .05; $p\eta^2$ = .03], and the interaction type of stimulus by group [$F_{(2,30)}$ = 1.68; p> .05; $p\eta^2$ = .10] were not significant. Penultimate final sequence words were bisected more rightwards than antepenultimate final sequence words, without differences between groups.

Comparing the shifts in the penultimate and antepenultimate final sequence word conditions for each patient, with those of healthy participants, patients GP and LA showed significant rightward biases for both types of stimuli (GP: penultimate = +33.86%, $t_{(10)} = 8.51$, $p< .001$; antepenultimate = +23.06%, $t_{(10)} = 6.79$, $p< .001$; LA: penultimate = +10.55%, $t_{(10)} = 2.59$, $p< .05$; antepenultimate = +12.94%, $t_{(10)} = 3.80$, $p< .005$). PF showed significant rightward deviations only with penultimate final sequence words (8.84%, $t_{(10)} = 2.16$, $p< .05$), and not with antepenultimate ones (3.11%, $t_{(10)} = .88$, $p> .05$), BA exhibited leftward deviations for both types of stimuli (penultimate = -23.74%, $t_{(10)} = -6.11$, $p< .001$; antepenultimate = -25.40%, $t_{(10)} = -7.60$, $p< .001$). The errors of all other N+ patients did not differ from those of healthy controls ($p> .05$ for all comparisons). When comparing the difference between penultimate and antepenultimate final sequence words, as compared to the same average difference in the control group, GP exhibited a significant difference, with the rightward bias being reduced for antepenultimate than penultimate final sequence words ($t_{(10)} = 3.06$, $p< .01$). LA showed no differences ($t_{(10)} = 2.19$, $p> .05$).

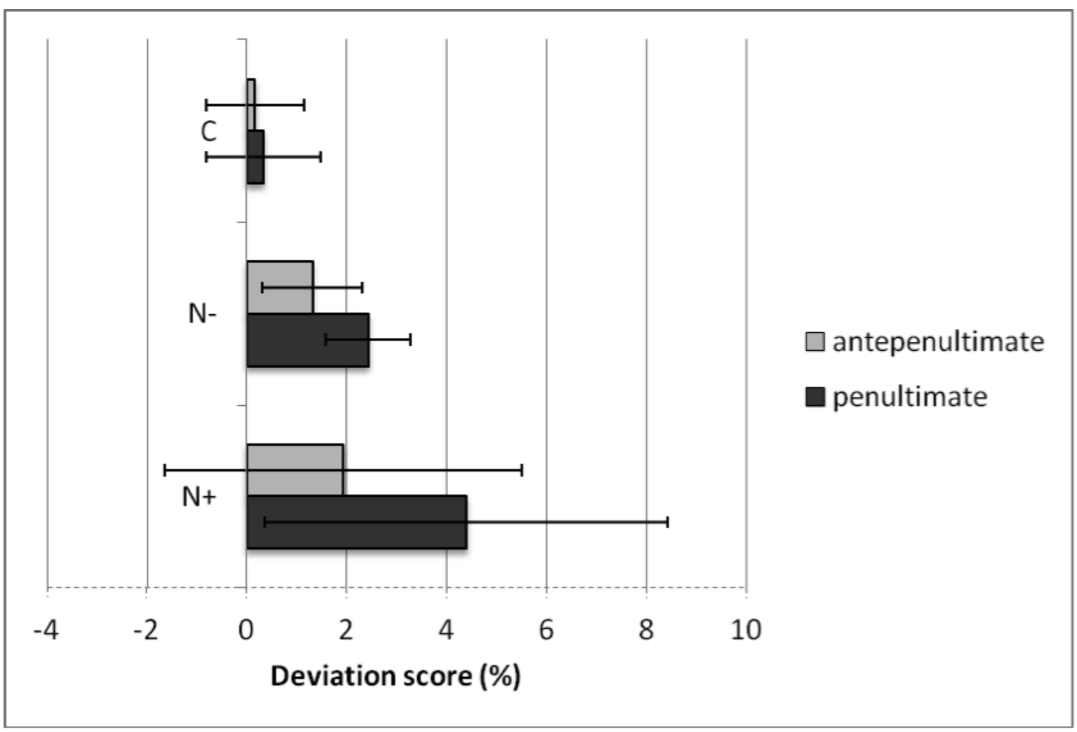

Figure 6. Study I, Experiment 2. Mean percent deviation error (±SE) by group (N+ and N- patients, and C participants), and by stimulus condition (penultimate final sequences: dark grey column; ante-penultimate: light grey column).

2.1.2. Discussion

In the present study, two experiments were performed in order to investigate how perceptual and lexical features influence the bisection of words in right brain-damaged patients with left USN, and whether identical or at least almost independent processing mediate the bisection of lines and orthographic material (Arduino et al., 2010). In Experiment 1 stimulus type (lines and words) and stimulus length (short, medium and long) were manipulated, while Experiment 2 focused on lexical features, like word stress. In Experiment 1, right-brain-damaged patients with USN, right-brain-damaged patients without USN and healthy matched participants were asked to bisect lines and words of different lengths. The results showed that USN patients exhibit, as a group, an average rightward error larger than controls, both patients and neurologically unimpaired subjects. Furthermore, a length effect for both types of stimuli (words and lines) was found: longer stimuli induced greater rightward directional biases. These results are in accordance with previous findings from line bisection tasks in patients with left USN (see Bisiach et al., 1983; Marshall & Halligan, 1989; Vallar et al., 2000; Daini et al., 2002), extending to words the length effect. Nevertheless, a perusal of the performances of individual patients shows that left USN can differently affect the bisection of words and lines. As patients MP, GP, and MA, patient DF shows a larger rightward bias with words, as compared with lines. Conversely, patient MV exhibits a rightward bias greater with lines. The different impact of spatial neglect on word and line bisection suggests the existence of different mechanisms underling the bisection behavior, which can be differently damaged by a right hemispheric lesion. In line with this view, healthy controls bisect rightwards long and medium lines, and leftwards long and medium words (see similar data in Arduino et al., 2010). The fact that pseudoneglect was reduced for lines in this group of unimpaired participants is in line with the literature, which suggests the hypothesis of a disproportionate aging of the right hemisphere compared the left hemisphere. This, in turn, would reduce hemispheric asymmetries, and the leftward bias of pseudoneglect typically showed by young subjects (Jewell & McCourt, 2000; Dolcos et al., 2002; Schmitz & Peigneux, 2011). With respect to patients without USN, an overall rightward bias for all types of stimuli was found, with the displacement increasing with length only in the case of lines and not for words. This pattern replicate for this group of patients the well-known length effect repeatedly found for lines in USN patients (e.g., Vallar et al., 2000).

In conclusion, the differential patterns of impairment exhibited by individual USN patients and the performance of control participants supported the hypothesis that, at least partly different processes are involved in word and line bisection (see also Arduino et al., 2010), although caution is needed due to the absence of a group effect. The difference between lines and orthographic strings may emerge early on in a lower-level processing stage, which detects the presence or absence of space between characters: an important responsible factor could be the difference between continuous (lines) and discrete (words) materials (Arduino et al., 2010). The bisection task explicitly requires a global processing of the stimulus extent, but in the case of discrete strings, a processing of the local features may be initiated.

Other studies have investigated how verbal material can be processed with different results. Using a task requiring to circle the central letter of very long character and symbol lines, Lee et al. (2004) report a systematic rightward error in neurologically unimpaired participants, and a stronger rightward displacement in right-brain-damaged patients with left USN. Similarly, in neurologically unimpaired participants, Mohr and Leonards (2007) show a rightward displacement in bisecting long letter lines in which words were inserted on the left, rather than on the right, of the veridical center. Nevertheless, both the type of stimuli and the task used are very different from those proposed in Fischer‘s and Arduino's studies (Arduino et al., 2010; Fischer, 1996, 2000a, 2000b, 2004), as well as in the present study.

In Experiment 2, the impact of linguistic information on word bisection was investigated. The results show that, when bisecting words containing those final sequences characterizing irregularly stressed stimuli, namely, with stress on the antepenultimate syllable, the three groups of participants exhibit a reduced rightward bias. With stimuli regularly stressed, a more rightward deviation is shown. The lack of differences among groups could be due to the short length of the stimuli used. In fact, the magnitude of the patients' bisection error is modulated by stimulus length (Vallar et al., 2000), and the mean length of both types of words (55.2 mm) is broadly comparable to the mean length of the short (44.6 mm) stimuli used in Experiment 1, in which group differences emerge only with longer words. Nevertheless, patient GP exhibits left USN with both types of stimuli, as compared to control participants, and he shows a minor rightward deviation with antepenultimate compared to penultimate final sequence words, replicating the stress effect found in the group analysis. This result demonstrates that orthographic and phonological information present in the right-hand side of the stimulus appears to be able to induce a leftward bias.

In conclusion, the results from the present study with patients with left spatial neglect provide evidence that the processing of the lateral extent of line and word stimuli is supported by at least partially independent processes, which can be differentially affected by brain damage. In the case of words the lexical information of word stress can be used as a cue during bisection, modulating bisection performance.

2.2. Study II. Bisection of words and lines radially oriented

The principal aim of this study was to investigate how written words are explored and represented using a bisection task. In particular, a non-canonical orientation of the stimulus may modulate the bisection performance in right brain-damaged patients with USN. An observer being faced with a misoriented word will be engaged in a process of imagining the rotation of the stimulus to upright for further processing (Koriat & Norman, 1984; Jordan & Huntsman, 1990), while there is no clear evidence for a translation of radial lines in an horizontal canonical format in bisection. Accordingly, in the present study the prediction was made that, before being bisected, words might be rotated into an horizontal canonical format so that the upper side of a word corresponds to its left side, and its down counterpart to its right side. Manipulating stimulus length, we predict that healthy subjects will exhibit a pattern of results resembling the bisection of horizontal stimuli, i.e. a length effect limited to words (Arduino et al., 2010), with upward (left) deviations for long stimuli and downward (right) for short stimuli ones. On the contrary, radial-down lines do not have a direction and should not undergo such a rotation, being bisected upwards (Shelton et al., 1990; Geldmacher & Heilman, 1994; Jeerakathil & Kirk, 1994; Toth & Kirk, 1996; Chieffi, 1996). With regards to USN patients, one possibility is a downward deviation for both words and lines, induced by damage of the right hemisphere, which has a more distal bias (Weiss et al., 2000). More interestingly, USN could differently affect the bisection of orthographic material and lines: it could be possible that USN patients would exhibit a downward bisection only in the case of words (and not for lines), as an expression of a rightward shift of attention after word rotation.

In the present study a group right-brain-damaged N+ patients, right-brain-damaged N- patients, and C participants were asked to manually bisect words of different lengths (short: 5 letters, and long: 10 letters) and comparable lines radially oriented (see Figure 7).

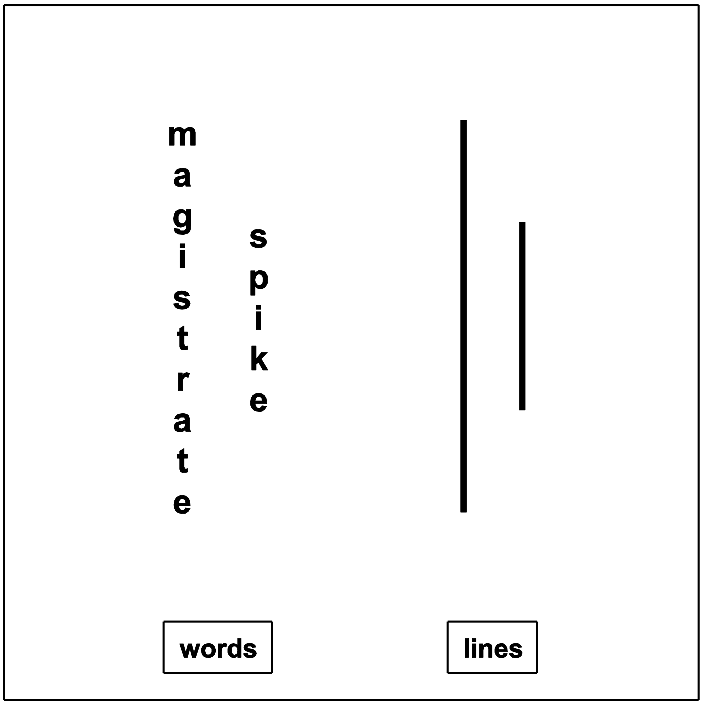

Figure 7. Examples of stimuli used in Experiment 2.

2.2.1. Experiment

2.2.1.1. Participants

Participants were recruited from the inpatient population of the Casa di Cura Privata del Policlinico, Milan (Department of Neuro-Rehabilitative Sciences) and of the Fondazione S. Lucia IRCCS, Rome (Research Centre on Neuropsychology). A total of 8 N+ patients, 7 N- patients, and 8 matched healthy controls participated in the experiment. The right-hemisphere-damaged patients had suffered a cerebrovascular stroke. The N+ sample included 4 females and 4 males, with a mean age of 68.5 years (SD ±8.14, range 57–79), and a mean education of 10.38 years (SD ±5.3, range 5–18). Mean duration of disease was 2.1 months (SD ±1.7, range 1–6). The N- group included 2 females and 5 males, with a mean age of 69.9 years (SD ±13.1, range 44–78), and a mean education of 10.9 years (SD ±5.30, range 5–17). Mean duration of disease was 1.3 months (SD± .8, range 1–3). The C participants were matched for sex (5 females, 3 males), age (M = 68.3, SD ±7.2, range 57–76), and education level (M = 10.0 years, SD ±3.9, range 5–17). Age [$F_{(2,22)}$= .06; $p>$ .05; $p\eta^2$= .01], and education level [$F_{(2,22)}$= .06; $p>$ .05; $p\eta^2$= .01] did not differ between groups. Furthermore, duration of the disease did not differ between N+ and N- patients [t_{13} = 1.11; $p>$ .05]. For each right brain-damaged patient the lesion site was assessed by CT or MRI scan and drawn manually using the MRIcro software (Rorden & Brett, 2000) onto selected horizontal slices of a standard template brain. Overlapped lesion maps of the 15 right-brain-damaged patients, subdivided in N+ and N- group are shown in Figure 8. In N+ patients' lesions superimposed in the white matter underneath the frontal inferior operculum, the precentral gyrus, the rolandic operculum, the supramarginal gyrus, and the postcentral gyrus (8 patients); in N- patients a maximum overlap was observed in the white matter underneath the insula (4 patients). Lesions were more extensive in the N+ (M volume = 111.1 cc, SD ±80.0) than in the N- group (M volume = 10.8 cc, SD ±10.9; $t_7 = 3.51$, $p < .01$).

All patients were right handed on a standard questionnaire (Oldfield, 1971), had normal or corrected-to-normal vision, and had no history of previous neurological diseases and psychiatric disorders. They were also given a Mini Mental State Examination (MMSE, Folstein et al., 1975) and their scores (N+ patients: M score 26.0, SD ±.9, range 25-27; N- patients: M score 27.3, SD ±2.5, range 25-30) were above the adjusted cut-off of Magni et al. (1996). All patients showed preserved visual fields on Goldmann perimetry or on the confrontation test. Demographic and neurological information are shown in Table 3. Informed consent was obtained from all subjects prior to participation according with the Declaration of Helsinki (British Medical Journal, 302: 1194, 1991).

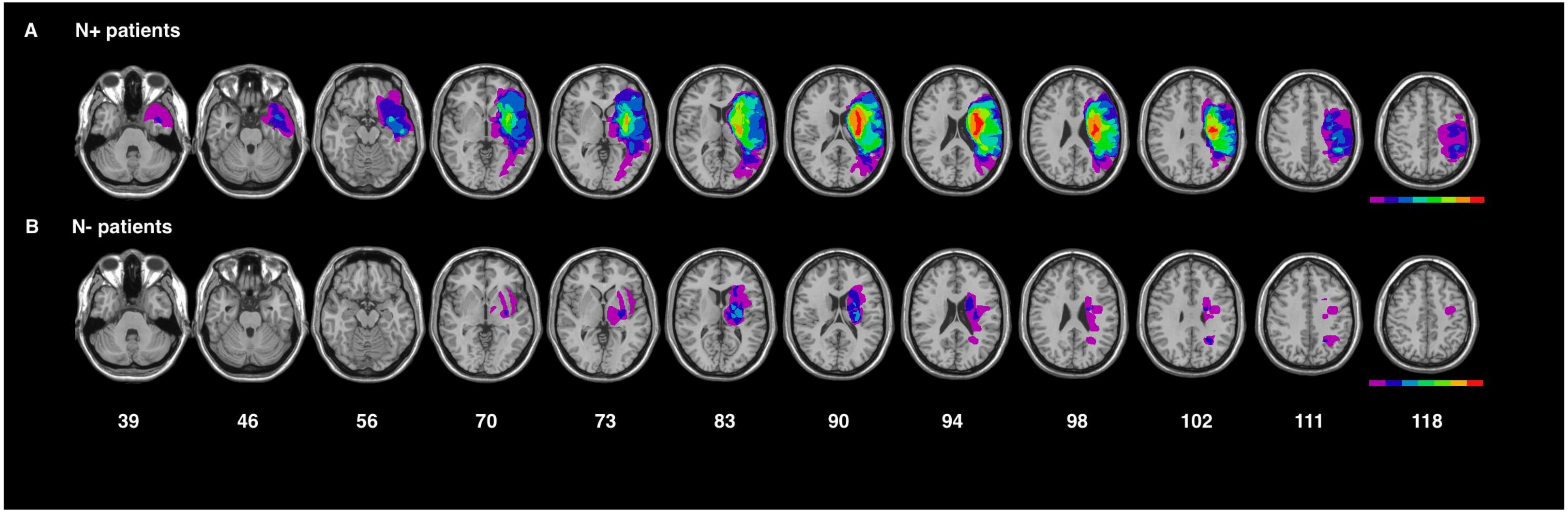

Figure 8. Study II. Superimposition of the right hemispheric lesions in 8 right-brain-damaged N+ patients (A), and in 7 right-brain-damaged N- patients (B). MNI coordinates for the shown axial slices are given. The number of overlapping lesions is illustrated by different colors coding increasing frequencies from violet (n = 1) to red (n = 8 for N+ patients; n = 7 for N- patients). Regions specifically damaged in right brain-damaged N+ patients mainly involved the white matter underneath the frontal inferior operculum, the precentral gyrus, the rolandic operculum, the supramarginal gyrus, and the postcentral gyrus.

Table 3. Study II. Demographic and neurological data of 8 right-brain-damaged N+ patients and 7 right-brain-damaged N- patients.

	Sex/Age/Education	Etiology/Lesion Site	Duration of disease (months)
N+ patients			
DF	F/69/8	I/ TFP	1
RF	M/61/18	I/TFPO	1
MV	M/79/5	I/ FT In	2
LE	F/72/13	I/ P	1
DMF	M/57/8	I/ FP In ic	1
MP	M/61/8	I/ TFP	2
GP	F/78/5	I/ T In Bg	2.5
VI	F/71/8	I H/ TFP	6
N- patients			
DI	F/44/13	I H/ FT In Bg	1
CE	M/78/13	I/ P	1
DA	M/75/13	I/ ic	1
VA	M/61/13	I/ t ic	1
FA	F/76/2	I/ Bg ec	1
LL	M/73/5	I/ P	3
CG	M/82/17	I/ Bg	1

M/F: male/female; I/H: ischemic/hemorrhagic lesion. F: frontal; P: parietal; T: temporal; O: occipital; In: insula; ic: internal capsule; ec: external capsule; Bg: basal ganglia.

2.2.1.2. Baseline neuropsychological assessment

The presence of unilateral visuo-spatial neglect was assessed using the same diagnostic battery as Study I. A pathological score in at least three tests was considered as an index of spatial neglect (see Fortis et al., 2010). The results of the assessment of visual USN and USN dyslexia are summarized in Table 4.

Table 4. Study II. Baseline assessment for left visual USN. Cancellation tasks: number of omissions in the left/right (L/R) hand-side of the display. Sentence reading: number of correct responses. Complex figure drawing: 10/10 indicates errorless performance. Clock drawing: total score ranged from 0 to 10. Line bisection: deviation in mm (-/+leftward/rightward deviation); percentage and number (in brackets) of neglect errors out of the total errors in word and nonword reading. Asterisks indicate defective performance, as compared with normative data.

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N+ patients												
DF	9/11*	0/10*	53/53*	47/51*	5/30*	0/26*	5/6*	3/10*	-6.44	9/10	0 (0/2)	.57* (4/7)
RF	9/11*	0/10*	47/53*	4/51*	5/30	4/26	3/6*	5/10*	-7.57	10/10	0 (0/1)	0.67* (10/15)
MV	6/11*	0/10*	43/53*	20/51*	30/30*	8/26*	5/6*	4/10*	21.36*	7/10	0 (0/2)	.5 (2/4)
LE	8/11*	0/10*	24/53*	16/51*	2/30*	0/26*	1/6*	5/10*	12.51*	9/10	0 (0/2)	.22 (2/9)
DMF	0/11	0/10	53/53*	31/51*	0/30	0/26	0/6	5/10*	10.5*	2.5/10*	0 (0/0)	0 (0/4)
MP	7/11*	0/10*	39/53*	4/51*	15/30*	2/26*	5/6*	5/10*	-5.18	10/10	1 (1/1)	.5 (1/2)
GP	1/11*	0/10*	53/53*	47/51*	3/30	3/26	2/6*	5/10*	-3.24	1/10*	0 (0/3)	.21 (3/14)
VI	4/11*	0/10*	53/53*	22/51*	30/30*	11/26*	4/6*	6/10*	3.89	3.5/10	0 (0/3)	.29 (4/14)

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N- patients												
DI	0/11	0/10	0/53	0/51	1/30	0/26	0/6	10/10	2.81	9.5/10	0 (0/0)	0 (0/2)
CE	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	4.96	7/10	0 (0/7)	.16 (3/18)
DA	0/11	0/10	0/53	0/51	1/30	0/26	0/6	10/10	5.54	10/10	0 (0/2)	.16 (1/6)
VA	0/11	0/10	1/53	0/51	0/30	0/26	0/6	10/10	2.69	10/10	0 (0/0)	0 (0/1)
FA	0/11	0/10	2/53	0/51	0/30	1/26	0/6	10/10	2.26	6/10	.28 (2/7)	.14 (3/22)
LL	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	2.09	8.5/10	0 (0/2)	0 (0/3)
CG	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	5.22	8.5/10	0 (0/0)	0 (0/0)

Note: n.a. = not assessed

2.2.1.3. Method

Stimuli and Procedure. The set of stimuli (40 Italian nouns) was the same of Study I, varying on length (20 short: 5-letter-long, and 20 long: 10-letter-long; see Appendix A). The medium word token frequency is 81 (range 5-226). Each word was printed in lowercase, 30-pt, Arial font on an A4 sheet, so that all letters were underneath each other, from top to bottom, with letter orientation preserved (see Figure 5). This orientation prevents head rotation induced by reading during the task with respect to 45°-rotated words (see Pashler, Ramachandran & Becker, 2006, for torsional eye movements induced by misoriented words). Five-letter words had a medium length of 56.4 mm (SD ± .9, range 55-58) and 10-letter words of 118.3 mm (SD ± .8; range 118-121). The distance between the extremely upward point of the first letter and the extremely downward point of the ultimate letter was measured to the nearest mm. Starting from these stimuli, a total of 40 lines matched for length one by one with the words were designed (2-pt in width). Words and lines were randomly presented to each participant while, in each condition, stimuli presentation followed a fixed randomized order. Stimuli were presented in a radial down orientation, in the center of a horizontal A4 sheet, each page containing five stimuli, with the center being aligned with the mid-sagittal plane of the subject's body at a viewing distance of 40 cm. A moveable window was used in order to present each stimulus one at a time. Patients were individually tested in a quiet room, with the experimenter sitting in front of them, and they were asked to bisect each word and line, marking the mid-point with the pencil using the unimpaired right-hand. Participant were informed that horizontal mark could be made in any point of the word, irrespective of whether the center fall between two letters or through a letter. No time limits were imposed and no feedback was given with respect to the accuracy of the response. The procedure described in Rode et al. (2006) was modified to calculate deviations, in order to equate the participants' error with respect to stimulus length. The distance between the down-end of each stimuli and the participant's mark was measured to the nearest mm. Each measure was converted into a standardized score (measured from the inferior half minus objective half/ objective half * 100). This percentage deviation yields positive values for upward deviations with respect to the objective midpoint of the stimulus, and negative values for downward deviations.

Statistical analyses. Average standardized scores were analyzed by repeated-measures ANOVAs with two within-subjects factors (type of stimulus and length), and one between-subjects factor (the groups of participants). In order to control for a possible effect of lesion size in determining the different bisection pattern in N+ and N- patients, an analysis of covariance (ANCOVA) on the patients' mean deviations was carried out, with group (N+, N-) as the between-subjects factor, and type of stimulus and length as the within-subjects factors, and lesion size as the covariate (mean-centered prior to the analysis). For every analysis, we calculated the partial Eta Squared (pη^2), which measures the proportion of the total variance that is attributable to a main factor or to an interaction (Cohen, 1973), and whenever necessary pairwise comparisons were performed with Student-Newman-Keuls' *post-hoc* multiple comparisons. Furthermore, each average standardized score was compared to the objective midline of the stimulus through one-sample T-tests. The level of significance was always set at $p < .05$.

2.2.1.4. Results

Figure 9 shows that N+ patients exhibited opposite bisection biases for words and lines, with a downward bias, i.e., below the objective midpoint, for words and an upward deviation, i.e., above the objective midpoint, for lines. N- patients and healthy controls bisected upwards all kinds of stimuli.

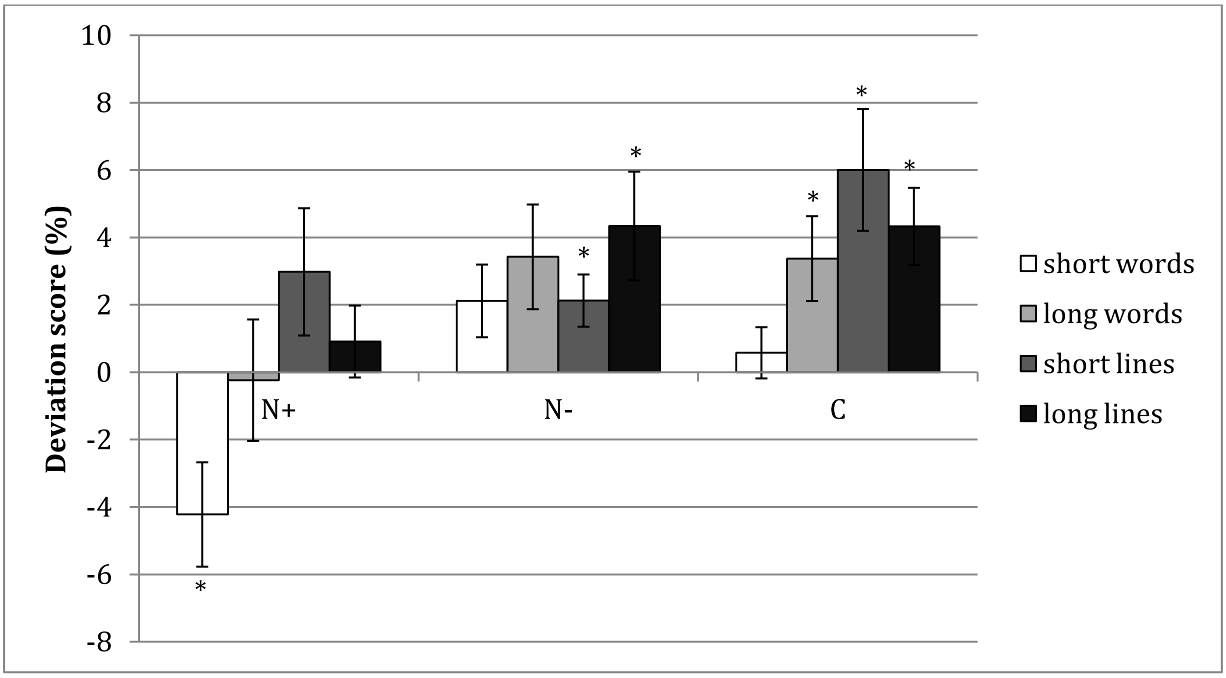

Figure 9. Study II. Mean percent deviation error (±Standard Error) made by N+ patients, N- patients, and controls (C), by type of stimulus condition (words and lines) and length condition (short words: white column; long words: light grey column; short lines: dark grey column; long lines: black column). Asterisks indicate performances different from accurate bisection.

In N+ group, performances differed from accurate bisection in the case of short words (deviation M = -4.22%, $t_{(7)}$= -2.72, $p < .05$), while no differences were found with respect to other types of stimuli (long words: M = -.24%, $t_{(7)}$= -.13, $p > .05$; short lines: M = 2.98%, $t_{(7)}$= 1.58; $p > .05$; long lines: M = .91%, $t_{(7)}$= .86, $p > .05$). The N- group showed errors differing from accurate bisection for lines of both lengths (short: M = 2.13%, $t_{(6)}$= 2.74; p< .05; long: M = 4.34%, $t_{(6)}$= 2.69, p< .05), and not for words (short: M = 2.12%, $t_{(6)}$= 1.96; p> .05; long: M = 3.43%, $t_{(6)}$= 2.20, p> .05). In the C group, performances differed from accurate bisection for short lines (M = 6.01%, $t_{(7)}$= 3.32; p< .01), long lines (M = 4.33%, $t_{(7)}$= 3.78, p< .01), and long words (M= 3.37%, $t_{(7)}$= 2.68; p< .05), while no significant differences were found in the case of short words (M = .58%, $t_{(7)}$= .76; p> .05).

Data were entered in a mixed ANOVA with Type of stimulus (words vs. lines) and Length (short vs. long) as within subject factors, and Group (N+ patients, N- patients, and C participants) as between subjects factor. The ANOVA revealed a significant main effect of group [$F_{(2,20)}$= 3.57; p< .05; pη²= .26], and type of stimulus [$F_{(1,20)}$= 12.25; p< .005; pη²= .38], while the main effect of length was not significant [$F_{(1,20)}$= 3.66; p> .05; pη²= .15]. The interactions type of stimulus by length [$F_{(1,20)}$ = 9.14; p< .01; pη²= .31], and type of stimulus by length by group [$F_{(2,20)}$= 3.80; p< .05; pη²= .27] were significant. The other interactions were not: type of stimulus by group [$F_{(2,20)}$= 2.13; p> .05; pη²= .18], and length by group [$F_{(2,20)}$= .37; p> .05; pη²= .04]. *Post-hoc* multiple comparisons revealed that, only in N+ group, short words were bisected nearer to the body (i.e., downwards), with respect to long words (M = -4.22% vs. M = -.24 %, p< .01), short lines (M = 2.98%, p< .001) and long lines (M = .91%, p< .005). In the N+ group short words were also different from deviations with long lines in the N- group (M = 4.34%; p< .05), and with lines of both length in the C group (short lines: M = 6.01%, p< .01; long lines: M = 4.33%; p< .05). No other significant differences were found (p> .05 for all comparisons).

Given the significance of the group by type of stimulus by length interaction, the participants' performances were further analyzed by three repeated-measures ANOVAs, in N+ patients, N- patients and healthy controls, with type of stimulus (words vs. lines) and length (short, 5 letters; long, 10 letters) as within-subjects factors. In the N+ group, the main effect of type of stimulus [$F_{(1,7)}$ = 9.71; p< .05; pη² = .58], and the type of stimulus by length interaction [$F_{(1,7)}$ = 7.22; p< .05; pη² = .51] were significant. The main effect of length [$F_{(1,7)}$ = .82; p> .05; pη² = .10] was not significant. *Post hoc* multiple comparisons revealed a significant difference between short and long words (M = -4.22% vs. M = -.24%; p< .05), and between short words and short (M = 2.98%), and long lines (M = .91%; p< .05 for both comparisons). No differences were found between all the other types of stimuli (p> .05 for all comparisons). In the N- patients group, the ANOVA revealed no significant main effect of type of stimulus [$F_{(1,6)}$ = .16; p> .05; pη² = .03], of length [$F_{(1,6)}$ = 3.82; p> .05; pη² = .39], and of the interaction type of stimulus by length [$F_{(1,6)}$ = .54; p> .05; pη² = .08]. In the control group, the main effect of type of stimulus [$F_{(1,7)}$ = 5.72; p< .05, pη² = .45], and the type of stimulus by length interaction were significant [$F_{(1,7)}$ = 6.77; p< .05; pη²= .42], while the main effect of length was not [$F_{(1,7)}$ = .33; p> .05, pη² = .04]. *Post hoc* multiple comparisons revealed a significant difference between short words and short lines (M = .58% *vs*. M = 6.01%, $p<$ .05), and short words and long lines (M = 4.33%; $p<$ .05), while the difference between short words and short lines was not significant (M = 3.37%, $p=$ .05). No differences were found between all the other types of stimuli ($p>$ .05 for all comparisons).

The ANCOVA revealed a significant main effect of lesion [$F_{(1,12)}$= 5.86; $p<$ .05; pη^2= .33], but importantly, the main effect of group [$F_{(1,12)}$= 4.92; $p<$ .05; pη^2= .29], and the interaction type of stimulus by length by group [$F_{(1,12)}$= 6.84; $p<$ .05; pη^2= .36] were significant. The main effect of the type of stimulus was also significant [$F_{(1,12)}$= 6.22; $p<$ .05; pη^2= .34], while the main effect of length was not [$F_{(1,12)}$= 3.60; $p>$ .05; pη^2= .23]. All the other interactions were not significant: type of stimulus by length [$F_{(1,12)}$ = 3.73; $p>$ .05; pη^2= .23], type of stimulus by group [$F_{(1,12)}$= 3.98; $p>$ .05; pη^2= .25], length by group [$F_{(1,12)}$= .30; $p>$ .05; pη^2= .02], type of stimulus by lesion [$F_{(1,12)}$ = .01; $p>$ .05; pη^2= .00], length by lesion [$F_{(1,12)}$ = .42; $p>$ .05; pη^2= .03], and type of stimulus by length by lesion [$F_{(1,12)}$ = 1.09; $p>$ .05; pη^2= .08].

In sum, N+ patients bisected short words downwards with respect to long words and lines of both lengths, for which upward deviations were found. On the contrary, N- patients and C participants bisected too far from the body all kinds of stimuli.

2.2.2. Discussion

In the present study, N+ patients, N- patients, C participants were asked to bisect words and lines of different lengths presented in radial down orientation. Both C participants and N- patients bisected upwards both types of stimuli, short and long. Deviations differed from accurate bisection for lines of both lengths and for long words in the C group, and only for lines, short and long, in the N- group. Importantly, N+ patients exhibited a downward deviation for short words, being accurate with long words and bisecting upwards lines of both lengths. The ANOVA results demonstrated that N+ patients bisected short words strongly downwards when compared to all the other types of stimuli. Furthermore, in the C group, the difference between short and long words, even if not significant ($p=$ .05), seems to mimic the "length effect" described by Arduino et al. (2010) in horizontal orientation: while lines were always bisected leftwards, long words were bisected leftwards and short ones rightwards. This result may suggest that participants could mentally rotate radial words anticlockwise during bisection, in which the "top" becomes the "left". The fact that such rotation occurs for words and not for lines is well expected due to the fact that words, but not lines, are typically experienced and processed along the horizontal axis (at least in most western countries). The upward deviation in the bisection of radial lines reported by healthy controls confirms what has been previously reported in the literature (Shelton et al., 1990; see also Chieffi, 1996; Jeerakathil & Kirk, 1994; Toth & Kirk, 1996). More critically, all subjects bisected lines and words differently: both stimulus type and stimulus length modulated the performance suggesting that stimuli undergo perceptual and/or linguistic processing during bisection. This stimulus type effect extends to radial presentation the hypothesis that at least partially independent processes are involved in the bisection of words and lines, as proposed by Arduino et al. (2010) for horizontally oriented stimuli.

The N- group bisected upwards all types of stimuli, with deviations different from accurate bisection limited to lines. N+ patients exhibited a downward deviation limited to words, more strongly when stimuli were short; on the contrary lines were bisected upwards. The mental rotation of stimuli from the radial to the horizontal orientation could be the reason for observing lateral asymmetries in the performance of left USN patients. This would occur more critically with short stimuli that could be easier rotated by patients. It would be possible that long words (10-letter-long) are too difficult to rotate for brain-damaged patients. An alternative explanation is that the downward deviation is induced by the damage of the right hemisphere, which has a more distal bias (Weiss et al., 2000), even more with linguistic and discrete material inducing a further activation of the left hemisphere. Nevertheless, lines induce a distal bias. Moreover, right-brain damage patients without USN did not show any downward bias with words as USN patients did. Thus, it appears more plausible that, in some patients, USN interacts at some point during the mental rotation of a word shifting the attention to the "bottom", which then becomes the "right".

In describing the reading performance of patient NG, Caramazza and Hillis (1990) argued that length is part of the cognitive representation of a word. Accordingly, this representation is orientation-invariant and its spatial reference frame is word-centered. On the contrary, according to Fischer (1996), stimulus orientation affects the spatial representation of orthographic stimuli: the vertical (radial) orientation should eliminate the leftward bias typically observed in horizontally presented words and this prediction has been confirmed in healthy subjects (Fischer, 1996). According to this author, the reference frame of word representation is normally not invariant with respect to the orientation of the represented stimulus. Moreover, he suggested that the spatial reference frame of this representation is not word centered, but overestimated at the beginning of the stimulus (e.g., Fischer, 1996, 2004). However, data from the present experiment showed that, even in radial down orientation, length differently modulates the bisection of words and lines, similarly to what observed in horizontal bisection in healthy participants. On this ground, it is possible to assume that when orthographic stimuli are non-conventionally oriented, such as when presented radially (top to bottom), they are mentally rotated activating a left-to-right word representation for bisection. Overall, our results are better explained within Caramazza and Hillis' framework (1990), which states that word representation is orientation-invariant and that length is part of the cognitive representation of word. Beyond the representative level, words are different with respect to lines since orthographic material is typically processed along the left-to-right direction, making more plausible a rotation from radial to horizontal during a bisection tasks, yielding a similar directional biases in both orientations. This mechanism interacts with visuo-perceptual features of the stimulus as well as with its linguistic processing, making bisection of words sensitive to more complex variables compare to line bisection.

In conclusion, the present study demonstrates that word processing undergoes additionally specific and culturally acquired mechanisms, such as the horizontal format in which words are normally experienced. Non-canonically oriented words processing could further imply a mental re-orientation along the horizontal axes, at least during a bisection task, increasing complexity of the mechanisms responsible for the directional errors described.

2.3. Study III. Bisection of sentences in unilateral spatial neglect

A first aim of the present study was to disentangle between linguistic and visuo-perceptual factors suggested for line and word bisection (Arduino et al., 2010, see also Study I, Experiment1 for data in USN patients). It is well known that the magnitude of the USN patients' bisection error is modulated by stimulus length, with a larger rightward displacement with longer lines (Bisiach et al., 1983; Marshall & Halligan, 1989): using stimuli longer than words, such as sentences, would permit to deeply unveil the linguistic and visuo-perceptual mechanisms underlying the bisection bias.

Secondly, in Study I (Experiment 2) both USN patients and controls are shown to use ortho-phonological information contained in the final part (right) of a word as a cue during bisection. Similarly, we predicted that USN patients could use the linguistic knowledge of a sentence during bisection, directing the allocation of attention and modulating the directional error in sentence bisection. In Experiment 1, USN patients and controls were required to bisect sentences differing on the syntactic structure (i.e., on the linguistic information contained in the rightward final position of the sentence, more attended by USN patients), compared to letter strings and lines. Recently, it has been shown that the syntactic structure of a sentence can reduce the tendency to omit words on the left in patients with USN dyslexia (Friedmann et al., 2011). The authors argued that shifting of attention could also be motivated by internal, linguistic factors. In particular, they found patients with text-based USN dyslexia committing fewer word omissions in reading sentences in which the final word was required by syntax, than in sentences that were grammatical even without the final word.

In the present study experimental manipulation included wh- questions differing on the position of the direct object (i.e., extracting the subject and with the object in final position or wh- questions extracting the object and thus with the object in initial position of the sentence), Yes-No questions and affirmative sentences, compared to letter strings and lines. We made the prediction that when the object of a sentence, that was mandatory for the transitive verbs used, was placed in initial position (pre-verbal), patients could not find it on the right, shifting attention leftwards. This cueing would yield a slighter rightward bisection error compared to sentences with the object placed in final position (right). Furthermore, in Italian the only difference between Yes-No questions and the same affirmative sentences is the presence, on the right, of the question mark. A difference in bisecting these two kinds of sentences would reveal a modulation of the allocation of attention cued by being interrogative of a sentence, through a possible phonological recoding of the sentence. The control condition included unreadable letter strings, mimicking the visuo-perceptual structure of a sentence, in terms of spaces between words. Furthermore, a set of continuous lines was included as a baseline condition. As previously suggested for healthy subjects and USN patients (Arduino et al., 2010; see also Study I, Experiment 1), a visuo-perceptual mechanism could contribute to a differential processing of linguistic strings (discrete) and lines (continuous).

In Experiment 2, patients and control participants were asked to bisect affirmative and interrogative sentences, sentences with altered lexicon (i.e., presence of pseudowords), and altered syntax (i.e., wrong order of the elements within a sentence), other than letter strings and lines. If no modulation (lexical- or syntactic-based) influences the allocation of attention with respect to correct sentences, a very basic linguistic mechanism would be responsible of sentence processing during bisection.

2.3.1. Experiment 1

2.3.1.1. Participants

Participants were recruited from the inpatient population of the Department of Neuro-Rehabilitative Sciences of Casa di Cura Privata del Policlinico, Milan, Italy. A total of 8 N+ patients, 8 N- patients and 8 C participants took part in the study. The right-hemisphere-damaged patients with USN had suffered a cerebrovascular stroke (6 ischemic, 2 ischemic with hemorrhagic infarction). The sample included 6 females and 2 males with a mean age of 77.4 years (SD ±5.95, range 68-86), and a mean education of 8.0 years (SD ±4.14; range 5-13). Mean duration of disease was 1.5 months (SD ±0.76, range 1-3). The N- patients had suffered an ischemic cerebrovascular stroke. The sample included 2 females and 6 males with a mean age of 74.6 years (SD ±7.33, range 61-87), and a mean education of 9.6 years (SD ±4.75; range 2-13). Mean duration of disease was 1.9 months (SD ±2.10, range 1-7). Eight C participants, 5 females and 3 males, matched for age (M = 77.9, SD ±5.46, range 70-85), and educational level (M = 8.8 years, SD ±3.73, range 5-13) participated in the study. One-way analyses of variance (ANOVAs) showed that age [$F_{(2,23)} = .62$; $p > .05$; pη² = .06], and educational level [$F_{(2,23)} = .30$; $p > .05$; pη² = .03] did not differ among groups (N+, N- and C). Furthermore, duration of the disease did not differ between N+ and N- patients [$t_{14} = -.47$; $p > .05$]. Lesion site was assessed for each right-brain-damaged patient by CT or MRI scan and drawn manually using the MRIcro software (Rorden & Brett, 2000) onto selected horizontal slices of a standard template brain. Overlapped lesion maps of 16 right-brain-damaged patients, subdivided in N+ and N- groups are shown in Figure 10. In N+ patients lesions superimposed in the right putamen and in the white matter underneath the insula, the rolandic operculum and the precentral gyrus (4 patients); in N- patients a maximum puntiform overlap was observed in the white matter underneath the postcentral gyrus (3 patients). Lesion volumes did not differ between groups (N+: M volume = 50.18 cc, SD ± 55.24; N-: M volume = 5.05 cc, SD ± 6.25; $t_7 = 2.29$, $p > .05$). Scan images were unavailable for N− patients SG and BA; medical records for these patients reported ischemic lesions in the white matter and in parieto-frontal areas, respectively.

Patients were right-handed on a standard interview (Oldfield, 1971), had normal or corrected-to-normal vision, and no history of previous neurological diseases or psychiatric disorders. Demographic and neurological information of the N+ and N- groups are shown in Table 5. All patients and controls were given a Mini Mental State Examination (MMSE, Folstein et al., 1975) and their scores (N+ M score = 26.3, SD ±1.29, range 25-28.7 ; N- M score = 26.1, SD ±1.57, range 24.7-29.4; C M score = 28.8, SD±1.50, range 26.7-30) were above the adjusted cut-off of Magni et al. (1996).

Table 5. Study III, Experiment 1. Demographic and neurological data of 8 right-brain-damaged N+ patients and 8 right-brain-damaged N- patients.

	Sex/Age/Education	Etiology/Lesion Site	Duration of the disease (months)	Neurological examination		
N+ patients				V	SS	M
MA	F/77/5	I H/ TF	2	ext	ext	+
RG	M/84/13	I/ PO	1	ext	-	+
PA	F/77/13	I/ Bg ic ec	1	ext	ext	+
DG	M/80/5	I/ Bg ic	2	-	-	+
QV	F/75/5	I/ T	1	-	-	+
IL	F/72/13	I/ TPF	1	-	+	+
PP	F/68/5	I/ F	3	-	-	+
RN	F/86/5	I H/ T	1	-	-	+
N- patients						
VAN	M/70/13	I/ cr	7	-	-	+
SG	M/74/5	I/ wm	1	-	-	+
BA	M/76/13	I/ PF	2	-	-	+
CA	F/87/5	I/ cr	1	-	-	+
CE	M/78/13	I/ P	1	-	-	+
DA	M/75/13	I/ ic	1	-	-	+
VA	M/61/13	I/ t ic	1	-	-	+
FA	F/76/2	I/ Bg ec	1	-	-	+

M/F: male/female; I/H: ischemic/hemorrhagic lesion. F: frontal; P: parietal; T: temporal; O: occipital; ic: internal capsule; ec: external capsule; Bg: basal ganglia; cr: corona radiata; t: thalamus; wm: white matter. Neurological examination: M/SS/V, motor/somatosensory/visual half-field deficit contralateral to the damaged hemisphere. ext, extinction to double simultaneous stimulation (for visual and somatosensory deficit). +, deficit; -, no deficit.

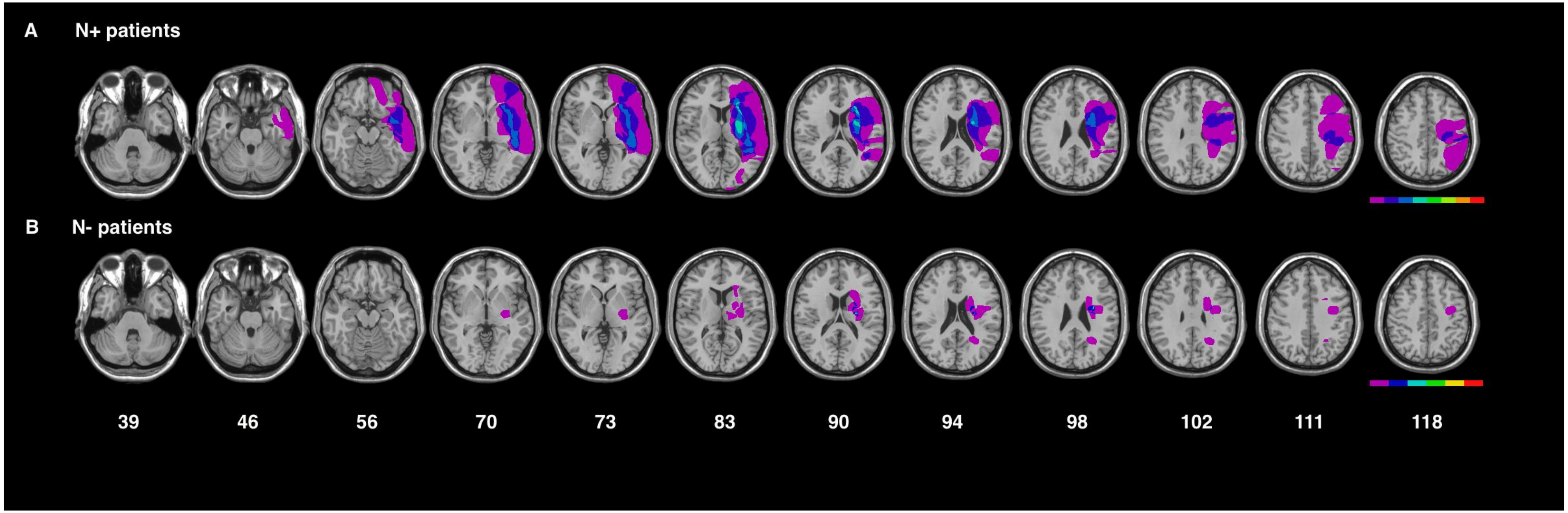

Figure 10. Study III, Experiment 1. Superimposition of the right hemispheric lesions in 8 right-brain-damaged N+ patients (A), and in 6 right-brain-damaged N- patients (B). MNI coordinates for the shown axial slices are given. The number of overlapping lesions is illustrated by different colors coding increasing frequencies from violet (n = 1) to red (n = 8 for N+ patients; n = 6 for N- patients). Regions specifically damaged in right brain-damaged N+ patients mainly involved the right putamen and in the white matter underneath the insula, the rolandic operculum and the precentral gyrus.

Twenty young healthy participants (YP; 12 females and 8 males) were also recruited. Mean age of the young group was 23.8 years (SD ±3.91, range 20-36), and mean education was 16.3 years (SD ± 1.52; range 14-18). Data obtained from the student group were further analyzed separately.

Informed consent was obtained from all participants, according with the Declaration of Helsinki (British Medical Journal, 302: 1194, 1991).

2.3.1.2. Baseline neuropsychological assessment

The same diagnostic battery for USN of Study I was used. A pathological score in at least one test was considered as an index of spatial neglect. Table 6 shows the results of the baseline assessment for N+ and N- patients.

2.3.1.3. Method

All participants were asked to manually set the midline of different kinds of sentences differing on their syntactic structure (i.e. presence or absence of obligatory linguistic information on the right), compared to letter strings and lines. A total of 240 stimuli were used, divided into six groups (40 items per group). Stimuli are shown in Appendix B.

i. 40 Wh- interrogative sentences using transitive verbs and extracting the object, thus with the object placed in the initial position of the sentence (Object questions). E.g. *Che quaderno smarrisce il professore?* (Which notebook does the teacher lose?). Considering that N+ patients could allocate more attention to the right of the stimulus, the lack of obligatory linguistic information on the right could modulate the attentional focus. When the obligatory object is placed in the initial position of the sentence, N+ patients could not find it in post-verbal position (on the right) and shift attention leftwards, committing a leftward bisection error compared to the condition in which the object placed in the final position of the sentence (right) (see condition ii).

Table 6. Study III, Experiment 1. Baseline assessment for left visuo-spatial neglect. Cancellation tasks: number of omissions in the left/right (L/R) hand-side of the display. Sentence reading: number of correct responses. Complex figure drawing: 10/10 indicates errorless performance. Clock drawing: total score ranged from 0 to 10. Line bisection: deviation in mm (-/+leftward/rightward deviation); percentage and number (in brackets) of neglect errors out of the total errors in word and nonword reading. Asterisks indicate defective performance, as compared with normative data.

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N+ patients												
MA	0/11	0/10	15/53*	5/51*	29/30*	10/26*	6/6*	2/10*	5.43	0/10*	0.27 (5/18)	0.18 (4/22)
RG	3/11*	0/10*	22/53*	12/51*	15/30*	8/26*	4/6*	2/10*	43.31*	7/10	1* (1/1)	0.57* (8/14)
PA	0/11	0/10	20/53*	9/51*	3/30*	0/26*	5/6*	7.5/10*	13.58*	2/10*	0 (0/4)	0.23 (4/17)
DG	0/11	0/10	3/53*	0/51*	0/30	0/26	0/6	10/10	9.56*	7/10	0.2 (1/5)	0 (0/11)
QV	4/11*	1/10*	36/53*	20/51*	17/30*	9/26*	6/6*	2/10*	43.78*	4/10	0.55* (16/29)	0.63* (24/38)
IL	8/11*	3/10*	31/53*	7/51*	22/30*	3/26*	4/6*	9.5/10*	19.37*	9.5/10	0.16 (1/6)	0.33 (7/21)
PP	0/11	0/10	1/53	2/51	0/30	0/26	0/6	9.5/10*	12.29*	4/10*	0.2 (1/5)	0.37 (9/24)
RN	0/11	0/10	3/53	2/51	3/30*	0/26*	0/6	9.5/10*	10.81*	9.5/10	0.16 (1/6)	0.38 (7/18)

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N- patients												
VAN	0/11	0/10	0/53	0/51	0/30	1/26	0/6	10/10	-1.42	8/10	0 (0/0)	0.28 (2/7)
SG	0/11	0/10	1/53	0/51	0/30	2/26	0/6	10/10	5.10	4/10	0.09 (1/11)	0.25 (6/24)
BA	0/11	0/10	0/53	1/51	1/30	0/26	0/6	10/10	-4.79	9.5/10	0 (0/2)	0.08 (1/12)
CA	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	0.42	8.5/10	0 (0/1)	0 (0/6)
CE	0/11	0/10	0/53	0/51	0/30	0/26	0/6	10/10	4.96	7/10	0 (0/7)	0.16 (3/18)
DA	0/11	0/10	0/53	0/51	1/30	0/26	0/6	10/10	5.54	10/10	0 (0/2)	0.16 (1/6)
VA	0/11	0/10	1/53	0/51	0/30	0/26	0/6	10/10	2.69	10/10	0 (0/0)	0 (0/1)
FA	0/11	0/10	2/53	0/51	0/30	1/26	0/6	10/10	2.26	6/10	0.28 (2/7)	0.14 (3/22)

ii. 40 Wh- interrogative sentences extracting the subject, with the object placed in the final position of a sentence (Subject questions). E.g. *Che alunno smarrisce il dizionario?* (Which student loses the dictionary?). In this condition the obligatory object is already on the right and no attentional shift was predicted according to linguistic knowledge (note that in Italian the subject of a sentence can be omitted). Nevertheless, if a leftward attentional bias would be found for both the types of questions discussed above, another possibility could be taken into account: a shift induced by the condition of a sentence to be interrogative rather than affirmative, indicated by the presence of a question mark on the right. Interrogative questions could undergo a phonological recoding that would modulate attention. In order to clarify the results in light of this possibility the following two conditions were introduced.

iii. 40 affirmative sentences with a full stop at the end. E.g. *La mamma smarrisce il portafoglio*. (The mother loses the wallet.).

iv. The same 40 sentences at point (iii) but interrogative (Yes/No questions). E.g. *La mamma smarrisce il portafoglio?* (Does the mother lose the wallet?). This type of stimuli were introduced because more comparable with the affirmative ones than types (i) and (ii), in which a wh- element was used. In Italian the only difference between conditions (iii) and (iv) is the presence of the question mark on the right. As previously discussed, a difference in the allocation of attention during bisection could be modulated by the interrogative nature of the sentence compared to affirmative ones, cued by the visual presence of the question mark on the right.

Wh- interrogative pronouns *Chi, Cosa, Che, Quale* (Who, What, Which) were used with the same frequency in sets (i) an (ii). Furthermore, verbs were the same within each stimuli set and noun frequencies in the left and right part of the sentences were balanced within and between sets of stimuli.

Control condition was:

v. 40 unreadable letter strings generated in order to mimic the visuo-perceptual structure of a sentence in terms of spaces between letters and the full stop. The presence of double letters was also maintained. Half of the stimuli were consonant strings, and half vowel strings. E.g. *Vbd fgnmrptc spdnnrdfg cv ngtrsddfrt*. or *Aoi auoi eooiuaie i aeuoieiae*.

Furthermore, a set of lines was introduced as baseline:

vi. 40 lines matched by length with the Wh- interrogative sentences (condition i). Lines could undergo differential processing during bisection compared to sentences and even letter strings: linguistic but also perceptual mechanisms would contribute to the differential bias shown in the bisection of words and lines in healthy participants (Arduino et al., 2010), and in USN patients (see Study I, Experiment 1), depending on their being continuous (lines) and discrete (words). Even if this point is not directly investigated in the present study, there could be a difference in bisecting sentences and letter strings, but also letter strings and lines. Considering that in neglect patients the rightward deviation increases with stimulus length (Bisiach et al., 1983; Marshall & Halligan, 1989), a different perceptual processing for letter strings and lines could be amplified with the stimuli used.

Different stimuli sets were randomly presented to each participant. Each stimulus was printed in lowercase, 26-pt, Arial font on an A4 sheet. Mean lengths for each condition were: (i and vi) M = 117.9 mm (SD± 18.0, range 87.0-158.5); (ii) M = 111.3 mm (SD± 18.0, range 80.0-151.5); (iii) M = 112.3 mm (SD± 13.9, range 82.0-139.5); (iv) M = 117.5 mm (SD± 13.8, range 88.0-145.0); (v) M = 114.2 mm (SD± 20.1, range 69.0-155.0). Stimuli were presented in the center of a horizontal A4 sheet, each page containing four, aligned with the mid-sagittal plane of the subject's body at a viewing distance of 40 cm. A moveable window was used in order to present each stimulus one at a time. Patients were individually tested in a quiet room, with the experimenter sitting in front of them. They were required to bisect each sentence, string or line, marking the mid-point with a soft pen using the right-hand, unimpaired in right-hemisphere-damaged patients. Participant were informed that the vertical mark could be made in any point of the stimulus, irrespective of whether the center might fall between two words, two letters or go through a letter. No time limits were imposed and no feedback was given with respect to the accuracy of the response. Deviations were calculated following the procedure described in Rode et al. (2006), as in Study I.

Statistical analyses. Young participants' average standardized score were analyzed separately by repeated-measures ANOVAs with one within-subjects factor (type of stimulus), considering the level of scholarship not comparable with old healthy subjects. Data from N+ patients were compared with N- patients and C participants by repeated-measures ANOVAs with one within-subjects factor (type of stimulus: object questions, subject questions, affirmative sentences, Yes/No questions, letter strings, lines), and one between-subjects factor (the groups of participants). The Greenhouse-Geisser correction for repeated-measured analyses (Greenhouse & Geisser, 1959) was used, in order to correct for violations of the sphericity assumption whenever necessary. For every analysis, we calculated the partial Eta Squared ($p\eta^2$), which measures the proportion of the total variance that is attributable to a main factor or to an interaction (Cohen, 1973), and whenever necessary pairwise comparisons were performed with Student-Newman-Keuls' *post-hoc* multiple comparisons. Furthermore, each average standardized score was compared to the objective midline of the stimulus through one-sample T-tests. The level of significance was always set at $p < .05$.

2.3.1.4. Results

As reported in Figure 11, young participants bisected all kinds of orthographic stimuli leftwards with respect to the objective midpoint of the stimulus, while they were quite accurate with lines and letter strings. Performances differed significantly from accurate bisection for all kinds of sentences (object sentences: deviation M = -1.67%, $t_{(19)}$= -2.67, p< .05; subject sentences: M = -1.69%, $t_{(19)}$= -2.59, p< .05; affirmative sentences: M = -1.50%, $t_{(19)}$= -2.76; p< .05; Yes/No questions: M = -2.49%, $t_{(19)}$= -3.83, p< .001), while no differences where found for letter strings (M = -.33%, $t_{(19)}$= -.64, p> .05), and lines (M = -.77%, $t_{(19)}$ = -1.13, p> .05).

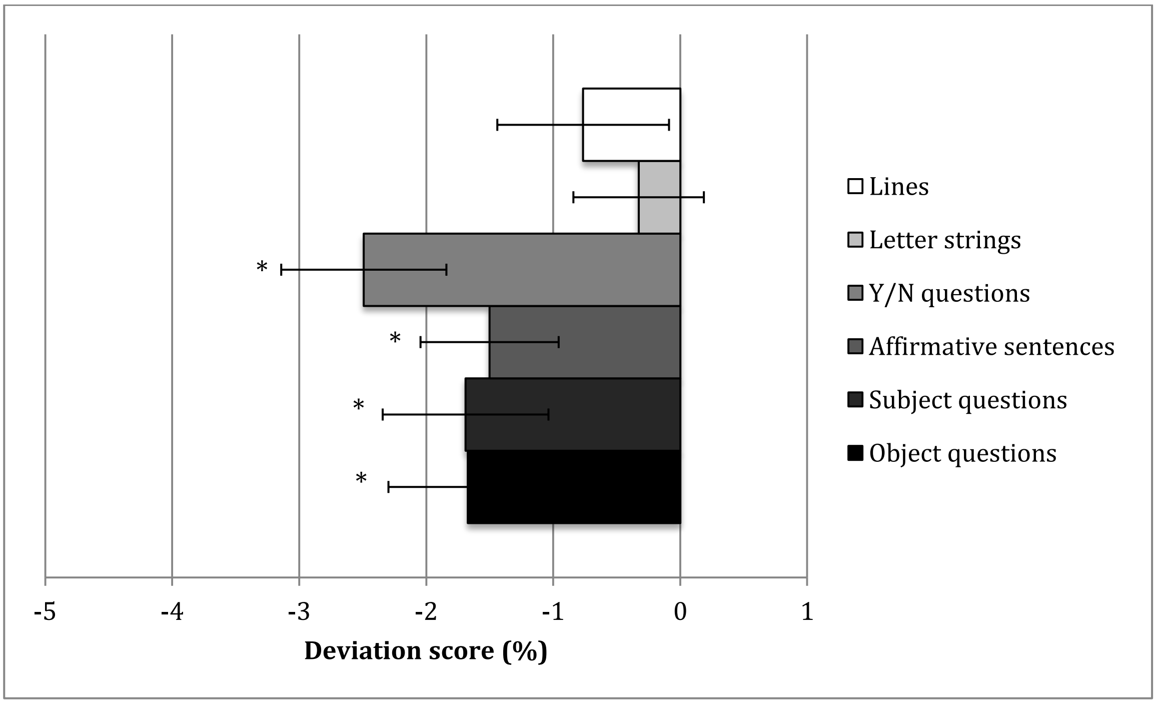

Figure 11. Study III, Experiment 1. Mean percent deviation error of the young participants by stimulus condition (lines, letter strings, Yes/No questions, affirmative sentences, subject questions, object questions). Asterisks indicate a deviation different from an accurate bisection.

The ANOVA revealed a significant main effect of type of stimulus [$F_{(3,45)}$= 3.45; p< .05; $p\eta^2$ = .15]. *Post hoc* multiple comparisons revealed exclusively significant differences between Yes-No interrogative sentences and both letter strings (M = -2.49% vs. M = -.33%, p< .005), and lines (M = -2.49% vs. M = -.77%, p< .05), while all the other comparisons were not significant (object questions: M = -1.67%; subject questions: M = -1.69%; affirmative sentences: M = -1.50%; p> .05 for all comparisons).

Globally, the group of young participants exhibited a leftward deviation for all kinds of stimuli, with a stronger error for sentences compared to letter strings and lines. This extends to sentences the stronger leftward bias demonstrated for words when compared to lines (Fischer, 1996; 2000a; 2000b; 2004; Arduino et al., 2010).

Figure 12 illustrated performances of the N+ patients, N- patients, and controls. C participants exhibited a leftward deviation for all kids of sentences, with an inversion of the bias for letter strings and lines. N- patients bisected interrogative Yes-No sentences to the left, they were accurate with affirmatives sentences, subject questions and object questions, and they showed a stronger rightward bias for both letter strings and lines. N+ patients exhibited an overall rightward bisection error modulated by type of stimulus, with a maximum deviation for lines, moderate for letter strings and slight for interrogative and affirmative clauses, independently from their syntactic structure.

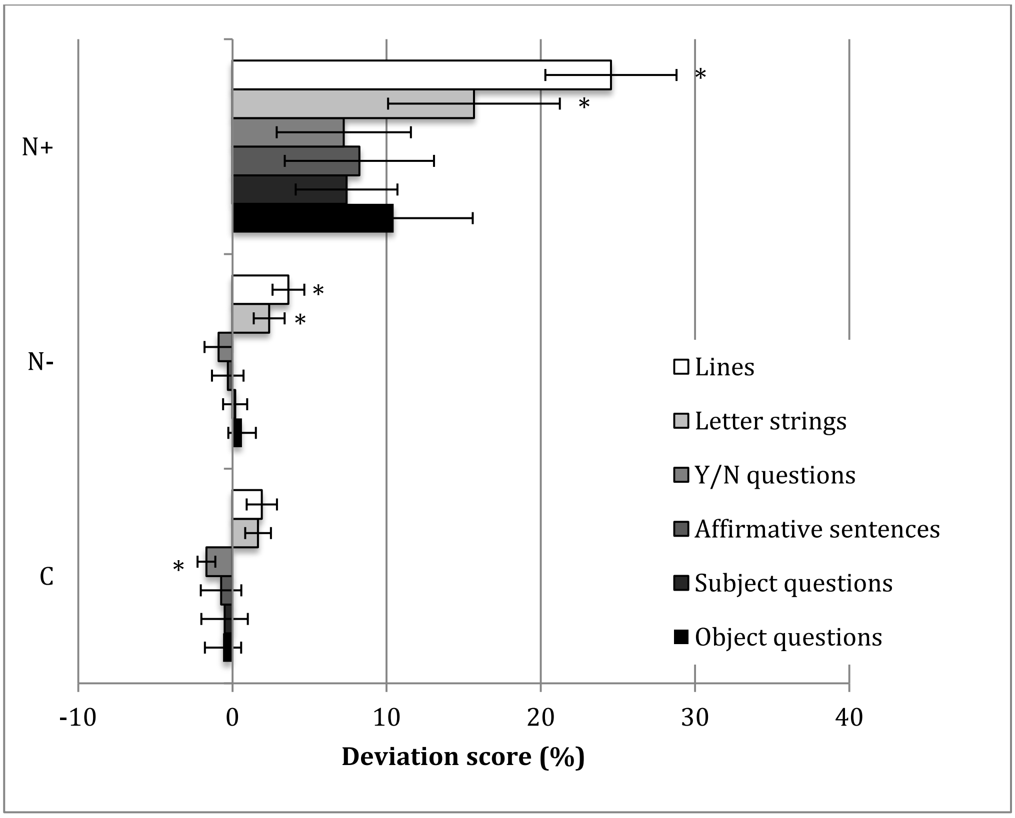

Figure 12. Study III, Experiment 1. Mean percent deviation error by group of participants (N+ patients, N- patients, and control subjects), and by stimulus condition (lines, letter strings, Yes/No questions, affirmative sentences, subject questions, object questions). Asterisks indicate a deviation different from an accurate bisection.

In the C group performances differed significantly from accurate bisection with a leftward bias only in the case of Yes-No questions (M = -1.67%, $t_{(7)}$= -2.90, p< .05), while there were no significant differences for all the other types of stimuli (object sentences: M = -.60%, $t_{(7)}$= -.51, p> .05; subject sentences: M = -.49%, $t_{(7)}$= -.33, p> .05; affirmative sentences: M = -.72, $t_{(7)}$= -.55; p> .05; letter strings: M = 1.68%, $t_{(7)}$= 2.01, p> .05; lines: M = 1.92%, $t_{(7)}$= 1.96, p> .05). Accordingly, N- patients showed rightward deviations significantly different from accurate bisection for letter strings (M = 2.40%, $t_{(7)}$= 2.39, p< .05), and lines (M = 3.65%, $t_{(7)}$= 3.54, p< .01), and not for all kind of linguistic material (object sentences: M = .64%, $t_{(7)}$= .72, p> .05; subject sentences: M = .19%, $t_{(7)}$= .24, p> .05; affirmative sentences: M = -.29%, $t_{(7)}$= -.28; p> .05; Yes-No questions: M = -.89%, $t_{(7)}$= -.98, p> .05). The N+ group bisected letter strings (M = 15.68%, $t_{(7)}$= 2.81, p< .05) and lines (M = 24.56%, $t_{(7)}$= 5.77, p< .005) significantly rightwards with respect to the objective midpoint of the stimulus, while performances with linguistic material did not differ from accurate bisection (object sentences: M = 10.47%, $t_{(7)}$= 2.04, p> .05; subject sentences: M = 7.42%, $t_{(7)}$= 2.25, p> .05; affirmative sentences: M = 8.25%, $t_{(7)}$= 1.70; p> .05; Yes-No questions: M = 7.24%, $t_{(7)}$= 1.66, p> .05).

Data were entered in a mixed ANOVA with the type of stimulus as within-subjects factor and the group of participants as between-subjects factor. The ANOVA revealed a significant main effect of Group [$F_{(2,21)}$= 8.76; p< .005; pη^2= .45], with an overall greater bias for N+ patients than for N- and C subjects (M = 12.27% vs. .95% and .02%, respectively). The main effect of type of stimulus was significant [$F_{(3,54)}$= 10.53; p< .001; pη^2= .33]. More interestingly, even the interaction type of stimulus by group [$F_{(10,105)}$= 3.14; p< .005; pη^2= .23] reached significance. *Post hoc* multiple comparisons revealed in the N+ group significant differences between lines and all the other conditions: lines and object sentences (M = 24.56% vs. M = 10.47%), lines and subject sentences (M = 7.42%), lines and affirmative sentences (M = 8.25%), lines and yes-no questions (M = 7.24%) and lines and letter strings (M = 15.68%, p < .005 for all comparisons). Significant differences were also found between letter strings and all the other conditions: letter strings and object questions (M = 15.68% vs. M = 10.47%, p< .05), letter strings and lines (M = 15.68% vs. M = 24.56%, p< .005), letter strings and subject sentences (M = 7.42%), letter strings and affirmative sentences (M = 8.25%), letter strings and yes-no questions (M = 7.24%, p< .01 for all comparisons). No differences were found between object sentences (10.47%), subject sentences (7.42%), affirmative sentences (8.25%) and yes-no questions (7.24%) (p> .05, for all comparisons). No significant comparisons were found in N- group: object sentences (.64%), subject sentences (.19%), affirmative sentences (-.29%), yes-no questions (-.89%), letter strings (2.40%), and lines (3.65%) did not differ each other (p> .05, for all comparisons). Even, in the C group no significant differences were found: object sentences (-.60%), subject sentences (-.49%), affirmative sentences (-.72%), yes-no questions (-1.67%), letter strings (1.68%), and lines (1.92%, p> .05, for all comparisons).

Globally, N+ patients exhibited facilitation in bisecting all kinds of sentences, when compared to letter strings and lines. In particular, the rightward directional bias was stronger with lines, moderate with letter strings and slight with all kinds of sentences, independently from their syntactic structure. In the C group, all sentences were bisected leftwards, with a rightward inversion of the bias for letter strings and lines. Note that young participants bisected leftwards all kind of stimuli with a stronger deviation for sentences. Accordingly, right-hemisphere-damaged N- patients showed a slight rightward shift with all kind of stimuli, when compared to C subjects, with a stronger bias to the right for letter strings and lines than for sentences.

2.3.2. Experiment 2

A new experiment was design in order to investigate if the facilitation found with all types of sentences, with respect to letter strings and lines, still remains after syntactic and lexical alterations within the sentences. If so, a very basic linguistic mechanism would be responsible of the attentional shift for sentences.

2.3.2.1. Participants

A new group of patients was recruited from the inpatient population of the Department of Neuro-Rehabilitative Sciences of Casa di Cura Privata del Policlinico, Milan, Italy. A total of 5 N+ patients, and 5 matched C participants took part in the study. N+ patients had suffered a cerebrovascular stroke (4 ischemic, 1 hemorrhagic). The sample included 3 females and 2 males with a mean age of 79.2 years (SD ±3.56, range 76-84), and a mean education of 7.20 years (SD ±3.49; range 5-13). Mean duration of disease in the 5 patients was 0.70 months (SD ±0.27, range 0.5-1). Lesion site was assessed for each right-brain-damaged patient by CT or MRI scan and drawn manually using the MRIcro software (Rorden & Brett, 2000) onto selected horizontal slices of a standard template brain. Single lesion maps of 3 right-brain-damaged patients are shown in Figure 13. Scan images were unavailable for patients LV and RF, with neuroradiological medical records reporting an ischemic lesion involving the right parieto-temporo-occipital regions, and the right internal capsule and basal ganglia, respectively. Five C subjects matched for age (M = 76.40, SD ±6.54, range 70-86), and educational level (M = 7.80 years, SD ±2.77, range 5-11) participated in the study. Age ($t_{(8)}$= .84, p> .05), and educational level ($t_{(8)}$= -.30, p> .05), did not differ between groups. Patients were right-handed on a standard questionnaire (Oldfield, 1971), had normal or corrected-to-normal vision, and no history of previous neurological and psychiatric disorders. All patients were given a Mini Mental State Examination (MMSE, Folstein et al., 1975) and their scores (M score = 25.58, SD ±1.08, range 24.2-26.7) were above the adjusted cut-off of Magni et al. (1996).

Demographic and neurological information for N+ patients are shown in Table 7. Informed consent was obtained from all participants, according with the Declaration of Helsinki (British Medical Journal, 302: 1194, 1991).

Table 7. Study III, Experiment 2. Demographic and neurological data of 5 right-brain-damaged N+ patients.

	Sex/Age/Education	Etiology/Lesion Site	Duration of the disease (months)	Neurological examination		
				V	SS	M
SM	F/77/13	I/ O	.5	+	-	+
PP	M/77/8	I/ O	1	+	-	+
LV	M/84/5	I/ PTO	.5	+	+	+
RF	M/76/5	I/ Bg ic	.5	-	-	+
CG	F/82/5	H/ T	1	-	-	+

M/F: male/female; I/H: ischemic/hemorrhagic lesion. P: parietal; T: temporal; O: occipital; ic: internal capsule; Bg: basal ganglia. Neurological examination: M/SS/V, motor/somatosensory/visual half-field deficit contralateral to the damaged hemisphere. +, deficit; -, no deficit.

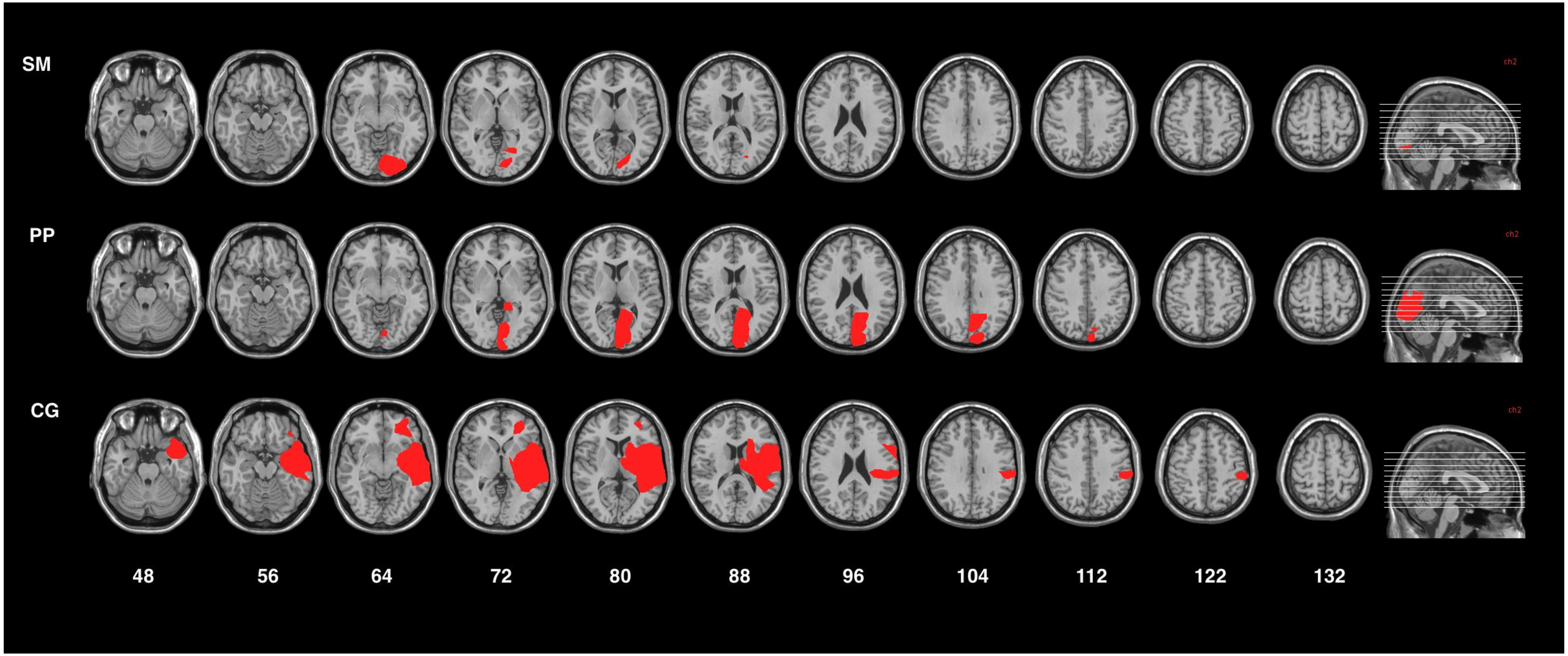

Figure 13. Study III, Experiment 2. Lesion maps of 3 right-brain-damaged N+ patients. MNI coordinates for the shown axial slices are given.

2.3.2.2. Baseline neuropsychological assessment

The presence and severity of USN was assessed using the same diagnostic battery described in Experiment 1. Table 8 shows the results of the baseline assessment for N+ patients.

2.3.2.3. Method

The experiment required the bisection of different types of sentences. A total of 240 stimuli were used (see Appendix B), divided into six groups (40 stimuli each). Stimuli sets were presented in a randomized order to each participant.

The task included: (i) 40 affirmative sentences (the same of the previous experiment); (ii) 40 Yes/No questions (the same of the previous experiment); (iii) 40 non-syntactic sentences; (iv) 40 non-lexical sentences; (v) 40 letter strings (the same of the previous experiment); (vi) 40 lines of comparable length. Non-syntactic sentences were generated half from the affirmative sentences, and half from the Y/N questions. The order of words in each sentence was randomized, with each element (subject, object, verb) occupying each sentence position (initial, central, final) with the same frequency. Furthermore, articles were separated from the relative nouns [e.g.: affirmative: *La mamma smarrisce il portafoglio*. (the mother loses the wallet.); non-syntactic: *Portafoglio il mamma smarrisce la*. (Wallet the mother loses the.)]. Non-lexical sentences were generated by changing letters in each word (in the left and right part of each word, minimum 2 letters, max all but 2 letters), without changing the order of the original words in the sentence. Specifically, keeping articles, verb endings/suffix, noun suffix with changes being confined to the root, gender/number agreement, consonant clusters and double consonants. [e.g.: *La cabba sterrisce il costapoglio*. (the loster sares the pibbet.). If the directional error showed by N+ patients with correct sentences increases in the case of altered lexicon, but not for altered syntax, patients would be guided leftwards by a lexical mechanism. If the directional error increases with non-syntactic sentences but not for non-lexical ones, a syntactic mechanism would guide patients leftwards. If both non-lexical and non-syntactic sentences eliminate the facilitation, it would be the sentence correctness crucial in inducing the leftward shift. If the directional error decreases for both non-lexical and non-syntactic sentences, in the same fashion as for correct sentences (and not for letter strings), a very basic linguistic mechanism, such as the possibility to read the stimulus would induce a leftward shift. For affirmative sentences, Yes/No questions, letter strings and lines mean length of the stimuli were the same of the previous experiment. Mean length of non-syntactic sentences was 116.9 mm (SD± 14.9, range 85.0-140.0); and of non-lexical was 116.2 mm (SD± 12.4, 90.0-148.5).

Procedure and scores were the same as the previous experiment.

Table 8. Study III, Experiment 2. Baseline assessment for left visual USN. Cancellation tasks: number of omissions in the left/right (L/R) hand-side of the display. Sentence reading: number of correct responses. Complex figure drawing: 10/10 indicates errorless performance. Clock drawing: total score ranged from 0 to 10. Line bisection: deviation in mm (-/+leftward/rightward deviation); percentage and number (in brackets) of neglect errors out of the total errors in word and nonword reading. Asterisks indicate defective performance, as compared with normative data.

	Line cancellation		Letter cancellation		Star cancellation		Sentence reading	Complex figure drawing	Line bisection	Clock drawing	Single word reading	
	L	R	L	R	L	R					word	nonword
N+ patients												
SM	11/11*	5/10*	53/53*	37/51*	30/30*	19/26*	6/6*	2/10*	73.71*	0/10*	n.e.	n.e.
PP	11/11*	1/10*	19/53*	15/51*	22/30*	15/26*	5/6*	4/10*	25.29*	7/10	0.19 (3/16)	0.44 (15/34)
LV	1/11	1/10	45/53*	5/51*	0/30	2/26	6/6*	4/10*	43.38*	6/10	0.64* (16/25)	0.87* (29/33)
RF	0/11	0/10	51/53*	13/51*	4/30*	1/26*	0/6	2.5/10*	11.93*	2/10*	0 (0/4)	0.37 (10/27)
CG	0/11	0/10	26/53*	1/51*	30/30*	13/26*	1/6*	.5/10*	17.03*	4/10*	0 (0/1)	0.6* (6/10)

n.e.: not evaluable

Statistical analyses. Data were analyzed by repeated-measures analysis of variance (ANOVA) with a within-subjects factor (type of stimulus: affirmative sentences, Yes-No questions, non-lexical sentences, non-syntactic sentences, letter strings, and lines), and a between-subjects factor (the groups of participants, N+ patients and controls). Pairwise comparisons were conducted with the Newmann-Keuls test. The level of significance was always set at .05.

2.3.2.4. Results

As shown in Figure 14, N+ patients exhibited a larger rightward deviation for lines, moderate for letter strings, and slight for all kind of sentences. C subjects bisected affirmative sentences and Yes-No questions to the left, and non-lexical, non-syntactic sentences, letter strings, and lines to the right.

In the N+ group, performances differed significantly from accurate bisection only in the case of letter strings (deviation M = 28.87%, $t_{(4)}$= 2.82, p< .05), and lines (M = 36.44%, $t_{(4)}$= 2.92, p< .05), while there were no significant differences for all the other types of stimuli (affirmative sentences: M = 16.98%, $t_{(4)}$= 1.75, p> .05; Yes/No questions: M = 20.10%, $t_{(4)}$= 1.73, p> .05; non-lexical sentences: M = 11.66%, $t_{(4)}$= 1.24; p> .05; non-syntactic sentences: M = 18.42%, $t_{(7)}$= 1.61, p> .05). C participants' performances did not differ from accurate bisection with all types of stimuli (affirmative sentences: M = -.65%, $t_{(4)}$= -.78, p> .05; Yes/No questions: M = -1.94%, $t_{(4)}$= -1.99, p> .05; non-lexical sentences: M = 1.14%, $t_{(4)}$= 1.78; p> .05; non-syntactic sentences: M = .15%, $t_{(7)}$= .09, p> .05; letter strings: M = .64%, $t_{(4)}$= .43, p> .05: lines: M = 1.56%, $t_{(4)}$= .98, p> .05).

The ANOVA revealed a significant main effect of type of stimulus [$F_{(2,40)}$= 6.81; p< .005; pη^2= .46], and the type of stimulus by group interaction [$F_{(2,40)}$= 5.53; p< .001; pη^2= .41], while the main effect of group [$F_{(1,8)}$= 4.44; p> .05; pη^2= .36] did not reach significance.

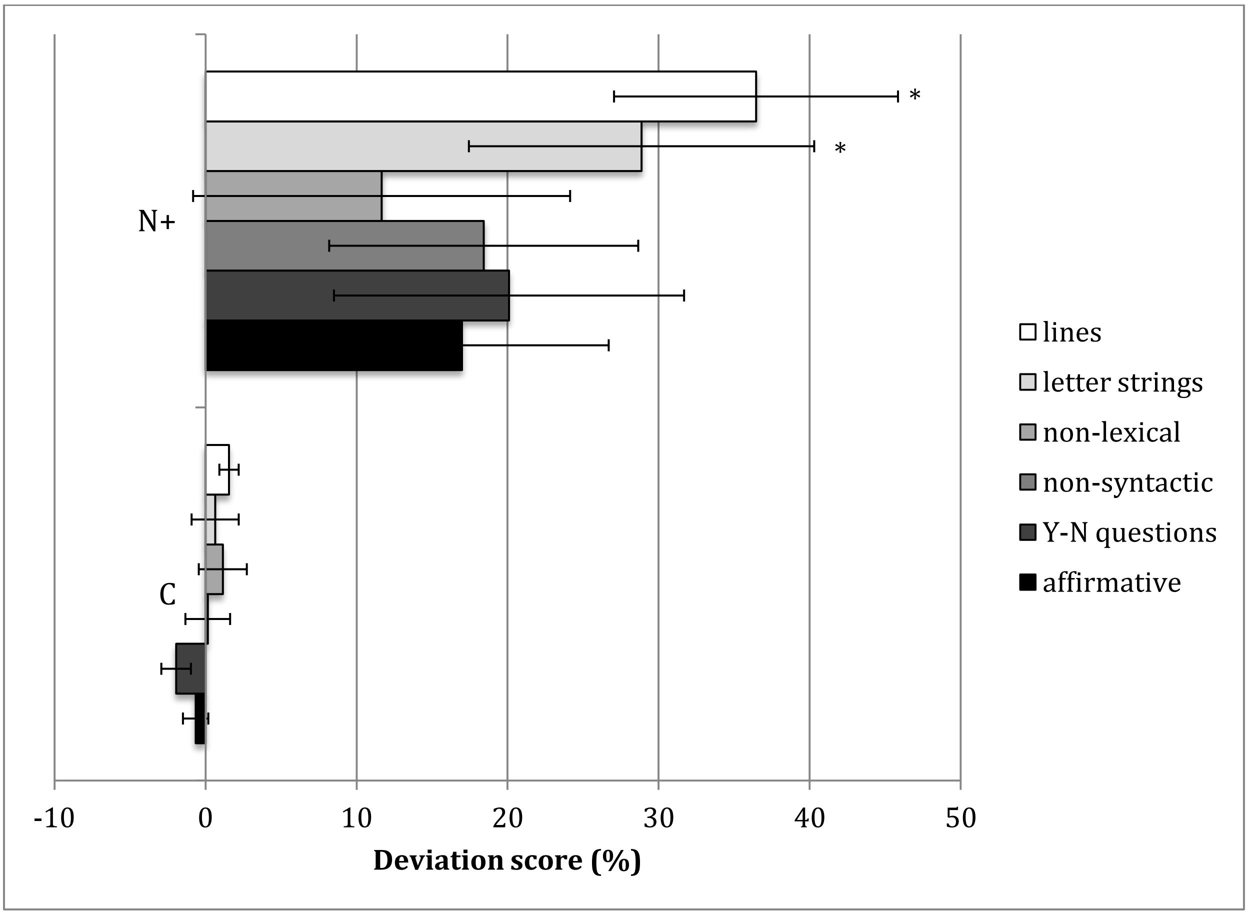

Figure 14. Study III, Experiment 2. Mean percent deviation error (±Standard Error) made by N+ patients, and controls (C), by type of stimulus condition (affirmative sentences, Y-N questions, non-syntactic sentences, non-lexical sentences, letter strings, and lines). Asterisks indicate a deviation different from an accurate bisection.

As the interaction type of stimulus by group, *post hoc* multiple comparisons revealed, only in the N+ group, significant differences between lines (M = 36.44%) and all the other kinds of stimuli (affirmative: M = 16.98%; Y/N questions: M = 20.10%; non-syntactic sentences: M = 18.42%; non-lexical sentences: M = 11.66%; letter strings: M = 28.87%; $p< .05$ for all comparisons), and between letter strings and all the other kinds of stimuli ($p< .05$ for all comparisons). No significant differences were found between affirmative, non-lexical, non-syntactic sentences, and Y/N questions ($p> .05$ for all comparisons). In the control group, stimuli did not differ each other (affirmative: M = -.65%; Y/N questions: M = -1.94%; non-syntactic sentences: M = .15%; non-lexical sentences: M = 1.14%; letter strings: M = .64%, and lines: M = 1.56%, $p> .05$ for all comparisons).

In sum, N+ patients showed a rightward bisection bias modulated by stimulus length, larger for lines, moderate for letter strings and slight for all kind of sentences, replicating the results of previous experiment.

2.3.3. Discussion

The present study was conducted in order to investigate if linguistic knowledge could modulate N+ patients' allocation of attention during visuo-spatial bisection of orthographic strings, as recently shown for reading (Friedmann et al., 2011). Right-hemisphere-damaged patients with left USN, right-hemisphere-damaged patients without USN, matched healthy controls and young participants were asked to manually bisect different types of sentences, compared to letter strings and lines.

In Experiment 1, sentences varied on the linguistic information contained in the right/final part (post-verbal), more attended by USN patients: wh- questions differing on the position of the direct object (i.e., extracting the subject and with the object in final position or wh- questions extracting the object and thus with the object in initial position of the sentence), Yes/No questions and affirmative sentences, which in Italian only differ by the presence of the question mark on the right.

Young participants exhibited a leftward deviation with all kinds of stimuli, stronger with sentences compared to letter strings and lines. These results extended to sentences the leftward deviation stronger for words than for lines reported in previous studies with healthy participants (Fischer, 1996; 2000a; 2000b; 2004; Arduino et al., 2010). The stronger leftward bias generalized to sentences supports the role of linguistic processing during a visuo-spatial task. No differences were found between types of sentences, indicating that differences in the syntactic structure do not modulate *per se* the bisection error. Opposite to what described by Fischer (1996; 2000a; 2000b; 2004) and Arduino et al., (2010), in a study with healthy participants Mohr and Leonards (2007) showed a rightward displacement in bisecting letter lines, but both the type of stimuli and the task used were different with respect to the ones of the present study.

When considering the group of controls matched by age with the patients, they exhibited a leftward deviation significantly different from accurate bisection only in the case of Yes/No questions; they were quite accurate with all the other types of sentences, showing an inversion of the bias to the right with letter strings and lines. As reported in Study I for words, these results extended to sentences what previously shown for lines, i.e., a reduced pseudoneglect exhibited by elder participants. These performances may be interpreted in the light of the hypothesis of a disproportionate aging of the right hemisphere compared the left hemisphere (Jewell & McCourt, 2000; Dolcos et al., 2002; Schmitz & Peigneux, 2011). In accordance with an involvement of the right hemisphere in bisection, N- patients showed a rightward shift of the directional error with all types of stimuli, exhibiting a rightward deviation different from accurate bisection with both letter strings and lines.

Compared to N- patients and C subjects, the N+ group demonstrated an overall rightward deviation for all type of stimuli, with a greater directional error for lines, moderate for letter strings and slight for sentences, in the same fashion for interrogative and affirmative ones. The reduced rightward deviations with orthographic stimuli confirm the role of the linguistic mechanism in sentence bisection, which shift the allocation of attention leftwards modulating the directional error, in line with left-to-right reading habits. As for the group of young participants, the absence of syntactic modulation was confirmed in the N+ group, as in N- and C participants. In Study I, it was demonstrated that the final part of a word (on the right) could act as a cue during bisection, modulating the bisection bias. The present results do not extend the possibility, in terms of linguistic modulations, to the information contained in the final part of a sentence: no differences were found between types of sentences in which the final part was more or less informative from a linguistic point of view.

Furthermore, N+ patients reported a greater deviation for lines than for letter strings. Even if this point was not addressed by this study, and lines and letter strings cannot be directly compared, space for speculation remains possible. The difference between letter strings and lines is orthographic, on one hand, and visuo-perceptual, on the other: letter strings are made up by discrete elements, while lines are continuous (Arduino et al., 2010). It is well known that in USN a more global level of processing could be impaired with respect to the local (Delis et al., 1986; Gallace et al., 2008). It could be possible that continuous stimuli are more difficult to be processed globally, i.e., considering the initial and final part together, by USN patients because of impaired disengaging mechanisms that are likely to maintain attention rightwards and induce a greater bisection bias. This hypothesis is supported by the fact that the same difference between letter strings and lines is not found in control groups, being confirmed as a specific pattern of USN patients. The hypothesis of an "orthographic" difference between letter strings and lines, as the core feature underling the different processing, seems less plausible. Nevertheless, other studied are needed to clarify this point. In a study by Lee et al. (2004), N+ patients bisected letter strings more rightwards when compared to lines, but this difference could be due to the kind of task required, which was not a simple manual bisection. More interestingly, even Lee et al. (2004) suggested the involvement of a local level of processing in letter string bisection when compared to lines. Finally, the possibility that the differences found in the bisection of letter strings and lines could be due to an illusionary effect (see Ricci, Calhoun, & Chatterjee, 2000) can be excluded by the fact that normal participants did not show it.

Experiment 2 was designed in order to replicate previous results, and to investigate if the facilitation found in the bisection of sentences by USN patients still remains even after lexical and syntactic alterations in the sentence. N+ patients and matched healthy controls were asked to bisect various kind of stimuli: affirmative sentences, Yes-No interrogative sentences, non-lexical sentences in which words were substituted with legal non-words, maintaining the syntactic elements, non syntactic sentences, in which the order of words was altered within the sentence, letter string and comparable lines. The N+ group demonstrated an overall rightward deviation for all type of stimuli, with a greater directional error for lines, moderate for letter strings and slight for all kinds of sentences, confirming the results of the previous experiment. No significant differences were found in the control group. The linguistic nature of the stimulus induces neglect patients to shift attention leftwards, yielding a reduction of the bias with respect to letter strings. This kind of facilitation remains even in the case of altered lexical and syntactic structure, but not with letter strings, suggesting the existence of a linguistic mechanism in act during the visuo-spatial task. First, the possibility of reading the sentence could explain these results: letter strings, from which sentences differ, are unreadable material. Secondly, even if no differences were found between non-syntactic sentences and all the other types of linguistic strings, it could be possible that participants may reconstruct the syntactic structure during bisection, exhibiting a reduction of the directional error even in no-syntactic condition. This would mean that not only lexical (see results of Experiment 2, Study I), but also syntactic information can be used by neglect patients to direct attention during bisection.

In conclusion, the present study demonstrated that the linguistic nature of the stimulus could shift leftwards the allocation of attention, inducing a reduction of the rightward directional error in neglect patients, with respect to letter strings and even to lines. This kind of facilitation could be founded on a very basic linguistic mechanism. Nevertheless, the possibility that the syntactic structure of the sentence may play a role, even if in some ways altered, cannot be excluded.

General discussion

Three studies were conducted in order to investigate the encoding of orthographic material during bisection, and to unveil how visuo-perceptual and linguistic features of the stimulus influence the allocation of attention during a length-estimating task. To these aims, different groups of patients with left USN, right-brain-damaged patients without USN and control participants were asked to bisect different types of orthographic strings: words of different lengths, words with different stressed-final sequences, radial-oriented words (top to bottom), and sentences varying on the syntactic structure and with lexical and syntactic alterations.

In the Experiment 1 of Study I, participants were asked to bisect words and lines of different lengths (short, medium, and long). The neglect group demonstrated a "length effect" similar for words and lines, with the bias increasing with stimulus length. This result extended to words the length modulation extensively reported for lines (Bisiach et al., 1983; Marshall & Halligan, 1989). Furthermore, in individual patients spatial neglect can affect the bisection of words and lines with various degrees of severity, demonstrating that at least partially independent mechanisms interact during bisection, both linguistic and visuo-perceptual (Arduino et al., 2010). This view is further supported by healthy controls' performances, in which deviations are rightwards for long and medium lines, and leftwards for long and medium words (see similar data in Arduino et al., 2010). In the Experiment 2 of Study I, participants were required to bisect words differing on the ortho-phonological information contained in their final part (right-side), which characterizes more regularly or irregularly stressed words. The results show that the three groups of participants exhibit a reduced rightward bias when bisecting words containing those final sequences characterizing irregularly stressed stimuli, namely, with stress on the antepenultimate syllable. Thus, the ortho-phonological information of a word could act as a cue during bisection, modulating the bisection error in both neglect patients and healthy subjects. This extends to a task different than reading, the lexical modulation reported in patients with USN dyslexia (Vallar et al., 2010, for review). The fact that no reliable lexical effects of written frequency on error deviation were found in previous studies (Arduino et al., 2010; Fischer, 1996) may be due to the fact that stimuli were presented with a limited time of exposure, which may have reduced word lexical processing. In this study using an unlimited time of exposure, patients may process the stimuli lexically, thus favoring the emergency of lexical effects (Arduino et al., 2006).

Study II addressed to how radial written words are explored and represented using a bisection task. In fact, the bisection performance in right brain-damaged patients with USN may be modulated by non-canonical orientation of the stimulus. The hypothesis was that, when being faced with a misoriented word (i.e., radially oriented from top to bottom), a subject could engage a process of imagining the rotation of the stimulus to upright for further processing (Koriat & Norman, 1984; Jordan & Huntsman, 1990). This process should be evident through a modulation of the directional bias during bisection. On the other hand, no clear is the evidence for a translation of radial lines in a horizontal canonical format during bisection. The results showed that neglect patients exhibited a larger proximal bias in the bisection of short radial words, and not for lines. This downward error fall in the rightward part of a word, mimicking the rightward deviation typically showed by patients with horizontal lines (Bisiach et al., 1976; Heilman et al., 1985; Vallar et al., 2000), and also with words (see Study I). This would suggest that, at least for some patients, radial words are rotated to reach their canonical orientation during bisection. The bias is clear only with short words, which would be easier to rotate than long ones. Healthy controls' performance are quite and large in accordance with this hypothesis, exhibiting a tendency to bisect upwards long words with respect to short ones, replicating what described by Arduino et al. (2010) in horizontal orientation. Overall, these results are in accordance with Caramazza and Hillis' hypothesis (1990) of an orientation-invariant representation of the words, with length being part of the cognitive representation (see also Fischer, 1996). Beyond the representative level, the present study demonstrates that non-canonically oriented words processing could further imply a mental re-orientation along the horizontal axes, at least in a bisection task, which can interact with spatial attentional processing, yielding an untypical expression of left spatial neglect in the bisection of radial words.

Finally, in Study III the linguistic modulation demonstrated in the bisection of words was extended to sentences. Patients and controls were asked to manually bisect different kind of sentences, in which the syntactic structure was manipulated, compared to letter strings and lines (see Friedmann et al., 2011, for a syntactic modulation of reading errors in neglect dyslexia). The results showed that the rightward bisection bias exhibited by patients with USN for lines could be reduced with letter strings and more importantly, with sentences, independently from their syntactic structure. The linguistic nature of the stimulus induces a kind of facilitation in USN patients, who shift attention leftwards in case of sentences, with respect to letter strings. This facilitation still remains even when lexical and syntactic alterations are introduced (see Experiment 2, Study III). However, even if no differences were found between non-syntactic sentences and all the other types of linguistic strings, participants may reconstruct the syntactic structure in the altered condition, and could be guided by this during visuo-spatial exploration of the stimulus. In fact, patients could be able to regularize sentences in which the order of the elements was changed. If so, this would extend to syntax the lexical modulation found for words in Study I (see results of Experiment 2).

In conclusion, a series of studies including patients with unilateral spatial neglect were conducted in order to investigate, for the first time, how words and sentences are processed during a non-linguistic, length-estimating task, as bisection. Globally, it was demonstrated that visuo-perceptual and linguistic information (both lexical and possibly syntactic), the last supported by the undamaged left hemisphere, can be used by right-brain damaged patients with USN, modulating the allocation of attention in word and sentence bisection.

Acknowledgments

I am grateful to Prof. G Vallar, Prof. MT Guasti, and Prof. LS Arduino for their guide, teaching, and support during my Ph.D. period. I also thank all the people who agreed to take part in the experiments and permit me to conduct these studies, for the patience and good will.

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Appendix A

Word sets of Study I, Experiment 1. In Study II, short (5 letter-long) and medium (10-letter-long) words were included (N= 5, 10).

5-letter-long: tasca, posta, gesto, monte, spesa, vetro, disco, poeta, fiore, borsa, cesto, perla, nuora, spiga, tarlo, mensa, avena, fungo, amaca, talpa.

10-letter-long: conferenza, equilibrio, patrimonio, magistrato tecnologia, entusiasmo, inflazione, dimensione, contributo, superficie, parsimonia, pneumatico, mascalzone, crepuscolo, camaleonte, partigiano, didascalia, proboscide, rimprovero, coriandolo.

12/13-letter-long: distribuzione, proprietario, informazione, testimonianza, disperazione, comunicazione, circolazione, imprenditore, parlamentare, responsabile, mobilitazione, verniciatura, prestigiatore, centralinista, destinatario, registratore, razionalismo, orfanotrofio, trepidazione, comunicatore.

Study I, Experiment 1. List of words, number of letters (N) and lengths of words and comparable lines expressed in mm (L). In Study II, short (5 letter-long) and medium (10-letter-long) words were included (N= 5, 10).

	Word	**N**	**L**
1	fiore	5	34
2	tasca	5	43
3	poeta	5	45
4	posta	5	44
5	vetro	5	41
6	monte	5	51
7	disco	5	43
8	borsa	5	45
9	spesa	5	49
10	gesto	5	45
11	spiga	5	44
12	fungo	5	45
13	avena	5	50
14	amaca	5	55
15	tarlo	5	35
16	talpa	5	38
17	perla	5	40
18	cesto	5	44
19	nuora	5	46
20	mensa	5	55
21	tecnologia	10	84
22	inflazione	10	78

	Word	N	L
23	contributo	10	82
24	dimensione	10	96
25	entusiasmo	10	96
26	patrimonio	10	87
27	equilibrio	10	75
28	conferenza	10	92
29	superficie	10	80
30	magistrato	10	87
31	camaleonte	10	97
32	mascalzone	10	100
33	didascalia	10	83
34	crepuscolo	10	91
35	parsimonia	10	91
36	partigiano	10	82
37	pneumatico	10	96
38	proboscide	10	91
39	coriandolo	10	86
40	rimprovero	10	89
41	disperazione	12	107
42	testimonianza	13	115
43	imprenditore	12	104
44	distribuzione	13	105
45	circolazione	12	99
46	parlamentare	12	110
47	proprietario	12	95
48	comunicazione	13	126
49	informazione	12	107
50	responsabile	12	106
51	trepidazione	12	101
52	razionalismo	12	105
53	comunicatore	12	113
54	centralinista	13	100
55	prestigiatore	13	103
56	verniciatura	12	97
57	destinatario	12	97
58	orfanotrofio	12	95
59	registratore	12	94
60	mobilitazione	13	109

Word sets from Study I, Experiment 2:

Penultimate final sequence words: alloro, ardita, canora, castoro, decoro, dimora, eremita, fallita, malora, papiro, parassita, ristoro, salita, sonoro, traforo, acrobata, angora, bibita, canfora, cernita, decrepita, forfora, fosforo, logoro, onnivoro, pecora, porpora, satiro, tacita, tortora.

Antepenultimate final sequence words: atomica, bambola, bussola, fertile, fossile, muscolo, organica, ostacolo, pascolo, pugile, rettile, sogliola, tattile, tessile, tipica, badile, barile, capriola, cazzuola, fienile, fucile, mollica, ortica, ostile, pignolo, pistola, sedile, tritolo, usignolo, vescica.

Study I, Experiment 2. List of words, stressed final sequence (StrSeq): penultimate (p) vs. antepenultimate (a); lengths of words and comparable lines expressed in mm (L).

	Word	StrSeq	L
1	alloro	p	45
2	ardita	p	45
3	canora	p	56
4	castoro	p	61
5	decoro	p	57
6	dimora	p	56
7	eremita	p	61
8	fallita	p	41
9	malora	p	55
10	papiro	p	51
11	parassita	p	74
12	ristoro	p	51
13	salita	p	42
14	sonoro	p	57
15	traforo	p	53
16	acrobata	p	72
17	angora	p	57
18	bibita	p	43
19	canfora	p	61
20	cernita	p	55
21	decrepita	p	76
22	forfora	p	52
23	fosforo	p	56
24	logoro	p	51
25	onnivoro	p	72
26	pecora	p	55
27	porpora	p	63
28	satiro	p	45
29	tacita	p	42

	Word	StrSeq	L
30	tortora	p	52
31	atomica	a	65
32	bambola	a	70
33	bussola	a	63
34	fertile	a	44
35	fossile	a	52
36	muscolo	a	69
37	organica	a	71
38	ostacolo	a	69
39	pascolo	a	63
40	pugile	a	49
41	rettile	a	45
42	sogliola	a	62
43	tattile	a	43
44	tessile	a	51
45	tipica	a	42
46	badile	a	49
47	barile	a	44
48	capriola	a	65
49	cazzuola	a	73
50	fienile	a	47
51	fucile	a	42
52	mollica	a	56
53	ortica	a	45
54	ostile	a	43
55	pignolo	a	59
56	pistola	a	52
57	sedile	a	48
58	tritolo	a	44
59	usignolo	a	69
60	vescica	a	62

Appendix B

Sets of stimuli used in Study III. Lengths of stimuli expressed in mm (L).

Experiment 1: Object questions, Subject questions, Affirmative sentences, Yes/No questions, Letter strings, and Lines (not reported).

Experiment 2: Affirmative sentences, Yes/No questions, Non-syntactic sentences, Non-lexical sentences, Letter strings, and Lines (not reported).

	Object questions	**L**
1	Che gruppo sceglie lo studente?	132
2	Cosa utilizza l'idraulico?	98
3	Cosa trova il postino?	88
4	Cosa distrugge il manifestante?	129
5	Cosa ripara il nonno?	87
6	Che ordine impartisce il vigile?	125
7	Cosa avvista il cacciatore?	111
8	Cosa ottiene il cliente?	92
9	Quale armadietto svuota la ballerina?	153
10	Cosa sostituisce il meccanico?	125
11	Che quaderno lancia l'alunno?	124
12	Cosa asciuga la cameriera?	114
13	Cosa cattura il bracconiere?	114
14	Cosa vede l'esploratore?	101
15	Cosa prenota il tirocinante?	112
16	Cosa colpisce il passante?	109
17	Cosa rovescia il fanciullo?	106
18	Cosa accorcia la sarta?	96
19	Che quaderno smarrisce il professore?	159
20	Cosa taglia il salumiere?	100
21	Cosa aggiusta lo scalatore?	113
22	Cosa spedisce lo zio?	89
23	Che affare conclude il medico?	126
24	Che mongolfiera ripara l'aviatore?	138
25	Cosa costruisce il muratore?	116
26	Che torta prepara la nonna?	115
27	Quale prassi cambia il governo?	131
28	Quale macchina rincorre la polizia?	144
29	Cosa semina il contadino?	107
30	Cosa scopre il paziente?	100
31	Che bevanda versa il barista?	122
32	Che galleria visita la scolaresca?	134
33	Che sciarpa raccoglie la ragazza?	139
34	Cosa rintraccia l'investigatore?	125
35	Quale confessione diffonde il pentito?	153
36	Cosa pulisce la badante?	103
37	Quale goal convalida l'arbitro?	123
38	Che armadio lucida il ragazzo?	126
39	Che maglione lava la nonna?	119
40	Che manuale vende l'editore?	122

	Subject questions	L
1	Che sposa sceglie il vestito?	115
2	Chi utilizza la bicicletta?	97
3	Chi trova la pistola?	80
4	Chi distrugge la cassettiera?	115
5	Chi ripara la gomma?	87
6	Che vigile impartisce l'ordine?	121
7	Chi avvista l'elicottero?	96
8	Chi ottiene l'aumento?	93
9	Quale allenatore svuota l'armadietto?	152
10	Chi sostituisce la lampadina?	118
11	Che insegnante lancia la penna?	133
12	Chi asciuga la forchetta?	100
13	Chi cattura il rinoceronte?	104
14	Chi vede l'arcobaleno?	93
15	Chi prenota lo spettacolo?	106
16	Che sasso colpisce la vetrina?	123
17	Chi rovescia l'aranciata?	99
18	Chi accorcia la gonna?	93
19	Che alunno smarrisce il dizionario?	142
20	Chi taglia il formaggio?	92
21	Chi aggiusta il lavandino?	104
22	Chi spedisce il pacco?	91
23	Che dirigente conclude l'affare?	129
24	Che artigiano ripara il cassetto?	129
25	Chi costruisce la muratura?	111
26	Che cuoca prepara la torta?	113
27	Che autista cambia la marcia?	123
28	Che poliziotto rincorre la macchina?	145
29	Chi semina il granoturco?	103
30	Chi scopre il vaccino?	89
31	Quale barista versa la bevanda?	132
32	Che dottore visita l'ambasciata?	130
33	Che bimba raccoglie l'orsetto?	123
34	Chi rintraccia la telefonata?	111
35	Che deputato diffonde l'annuncio?	139
36	Chi pulisce la cucina?	88
37	Chi convalida l'arresto?	95
38	Che atleta lucida la scarpa?	112
39	Quale famiglia lava la scala?	116
40	Che editore vende il gruppo?	117

	Affirmative sentences	L
1	Il padre sceglie i pantaloni.	105
2	Lo zio utilizza il martello.	96
3	La zia trova la rivista.	82
4	L’onda distrugge l’imbarcazione.	128
5	Il bimbo ripara la bici.	83
6	La maestra impartisce la lezione.	131
7	La tigre avvista l’elefante.	100
8	L’attrice ottiene il premio.	99
9	L’assistente svuota la cassettiera.	134
10	Il notaio sostituisce il documento.	131
11	La ballerina lancia la palla.	104
12	La nonna asciuga il bicchiere.	118
13	Il puma cattura il fenicottero.	112
14	Il toro vede il coccodrillo.	97
15	Il nonno prenota il ristorante.	112
16	La freccia colpisce il bersaglio.	121
17	La bimba rovescia la bottiglia.	127
18	La sarta accorcia la tenda.	104
19	La mamma smarrisce il portafoglio.	140
20	Il fabbro taglia la lamiera.	99
21	L’atleta aggiusta lo scarpone.	116
22	Il cliente spedisce la busta.	106
23	Il padrone conclude l'acquisto.	120
24	Il giornalista ripara l'errore.	105
25	Il marinaio costruisce la zattera.	125
26	Il delegato prepara la legge.	110
27	L’autista cambia il percorso.	110
28	Il rinoceronte rincorre la gazzella.	132
29	Il nipote semina il frumento.	109
30	Il dottore scopre il sintomo.	106
31	L'infermiera versa la minestra.	119
32	Il preside visita il mausoleo.	108
33	L'avvocato raccoglie la prova.	117
34	La banca rintraccia la chiamata.	126
35	La trasmissione diffonde la notizia.	137
36	La sarta pulisce il cappotto.	108
37	La giuria convalida la pena.	108
38	L'artigiano lucida la finestra.	110
39	La domestica lava la gonna.	111
40	Il libraio vende la rivista.	94

	Yes/No questions	L
1	Il padre sceglie i pantaloni?	110
2	Lo zio utilizza il martello?	101
3	La zia trova la rivista?	88
4	L'onda distrugge l'imbarcazione?	134
5	Il bimbo ripara la bici?	88
6	La maestra impartisce la lezione?	136
7	La tigre avvista l'elefante?	105
8	L'attrice ottiene il premio?	104
9	L'assistente svuota la cassettiera?	139
10	Il notaio sostituisce il documento?	137
11	La ballerina lancia la palla?	110
12	La nonna asciuga il bicchiere?	123
13	Il puma cattura il fenicottero?	117
14	Il toro vede il coccodrillo?	102
15	Il nonno prenota il ristorante?	118
16	La freccia colpisce il bersaglio?	127
17	La bimba rovescia la bottiglia?	123
18	La sarta accorcia la tenda?	109
19	La mamma smarrisce il portafoglio?	145
20	Il fabbro taglia la lamiera?	104
21	L'atleta aggiusta lo scarpone?	122
22	Il cliente spedisce la busta?	111
23	Il padrone conclude l'acquisto?	125
24	Il giornalista ripara l'errore?	110
25	Il marinaio costruisce la zattera?	131
26	Il delegato prepara la legge?	115
27	L'autista cambia il percorso?	116
28	Il rinoceronte rincorre la gazzella?	137
29	Il nipote semina il frumento?	114
30	Il dottore scopre il sintomo?	111
31	L'infermiera versa la minestra?	125
32	Il preside visita il mausoleo?	114
33	L'avvocato raccoglie la prova?	123
34	La banca rintraccia la chiamata?	132
35	La trasmissione diffonde la notizia?	143
36	La sarta pulisce il cappotto?	113
37	La giuria convalida la pena?	113
38	L'artigiano lucida la finestra?	115
39	La domestica lava la gonna?	116
40	Il libraio vende la rivista?	100

	Letter strings	L
1	Ptd bptrrs mptlfsg mq ztrgsbtp.	122
2	Btps lrtnrssm p pdfrtlnmg.	101
3	Cbns grpls pd rdftgnl.	84
4	Vsqz pdfrtpbbt sf nrstbdfpztnr.	118
5	Tdrf tbdspl ft dbrrt.	69
6	Prl rgntpm psrtndbfcg qt rgfdnm.	128
7	Tbvm pccsgrd mn bsddprgrtl.	114
8	Vbgf tppltsd lm bltrbtd.	88
9	Trnp sdbfgnrppl bvctr mt nsddrfgpm.	143
10	Bsfd pbmnstlgbfp ps bszzqbcrg.	127
11	Lpr sbpvptcg dfrqzp r hmnbbv.	121
12	Rtqd zcvbfgr sl mqnbplnrm.	108
13	Mbds nbttslr vr ptgmmgscvsd.	119
14	Sdfg ngmv p rtfdgpltbng.	97
15	Plds frtmpls zq btrpnimdbfr.	107
16	Pbvm fcgbnvps dl dsppcnbt.	111
17	Qcgb vgtbdcfs pl nbvgfrttl.	103
18	Dcvs zddfptvl mn drtsc.	92
19	Vbd fgnmrptc spdnnrdfg cv ngtrsddfrt.	150
20	Cbds fcvglt cl mdbngvrsf.	99
21	Aoui eooiuaie io aeuoieiae.	108
22	Ieui aeiuaoio ao ieo.	79
23	Iua oiiaeu iaueoiuo ei aoeieu.	116
24	Aue oiaeiuaoeao uaoeia a ieauoaui.	144
25	Uaiu aoeiueiaoe oa iaueouei.	115
26	Iae oeiua ouaieia ea iouua.	106
27	Euaoe ieuooa eiaieo ai euaoeia.	128
28	Ueaoe iaeeioua ueiaoeea ua eiuoaua.	152
29	Oaie uoauia ui eaieuaoeu.	104
30	Uoia euiaoi ia eioaiuei.	89
31	Uei eiaioai euioa eu ieaoeoa.	115
32	Aoi ieuuoeia iuoiua ue aoeuioaieo.	138
33	Iou euaeuoi eiaaueioi oa ieoaiia.	128
34	Euia oeiuaeuuia o iuaieiauoeioa.	129
35	Uaeoi aeuioaaeiuo ieuuoaie ui oeiaieu.	155
36	Ieoa uiaoeio au uoieuia.	94
37	Oaeiu euao ieuiaioui u aoeuiao.	126
38	Iao euoaiue ueioeo ue aoeiuuo.	125
39	Aou euaioeue iaoe ia eiuua.	111
40	Eie aoeiuoe euaie o aieueoi.	112

	Non-syntactic sentences	L
1	Sceglie i padre pantaloni il.	108
2	Zio martello il utilizza lo.	96
3	Trova la la rivista zia.	85
4	Imbarcazione onda la la distrugge.	138
5	Il Ripara bimbo la bici.	85
6	La la impartisce maestra lezione.	132
7	La elefante tigre avvista lo.	108
8	Ottiene attrice la premio il.	105
9	Svuota la cassettiera assistente la.	139
10	Il Sostituisce notaio documento il.	133
11	Palla ballerina la la lancia.	104
12	La Bicchiere il asciuga nonna.	119
13	Il cattura fenicottero puma il.	113
14	Coccodrillo toro il il vede.	100
15	Nonno ristorante il il prenota.	115
16	Bersaglio il la freccia colpisce.	121
17	Rovescia bimba bottiglia la la.	120
18	Sarta tenda la accorcia la.	105
19	Portafoglio il mamma smarrisce la.	139
20	La Fabbro lamiera il taglia .	103
21	Lo atleta scarpone aggiusta lo?	126
22	Cliente il spedisce busta la?	113
23	Il acquisto lo padrone conclude?	130
24	Ripara il errore lo giornalista?	118
25	La il costruisce zattera marinaio?	133
26	Il legge delegato prepara la?	115
27	Il autista percorso cambia lo?	118
28	Rinoceronte il gazzella rincorre la?	139
29	Il semina nipote frumento il?	113
30	Sintomo il scopre dottore il?	112
31	Versa infermiera minestra la la?	129
32	Il visita preside mausoleo il?	113
33	Prova avvocato lo raccoglie la?	125
34	La rintraccia banca chiamata la?	131
35	Notizia trasmissione diffonde la la?	140
36	Cappotto la il sarta pulisce?	112
37	Pena giuria convalida la la?	111
38	Lo finestra lucida artigiano la?	120
39	Domestica la lava gonna la?	114
40	Rivista il vende la libraio?	102

	Non-lexical sentences	L
1	Il sapre sciulbie i pendasoni.	113
2	Lo fiobo ubitilla il cardesso.	109
3	La rua driva la saverta.	92
4	L’urpa festragge l’oncagione.	117
5	Il senco pecara la timi.	90
6	La peostra ontarpisce la vorpine.	131
7	La secre orrasta l’ilerente.	104
8	L’opprite assiene il griscio.	107
9	L’addignente pluota la verracchiena.	146
10	Il fucato lontelisce il punafesto.	124
11	La ceddetira zarvia la rassa.	114
12	La ponna ortiuga il biorriete.	112
13	Il daga loppura il domicettero.	119
14	Il poso rede il seccoprillo.	102
15	Il goggo drisota il gescopinte.	117
16	La pribbia telcasce il sercigno.	122
17	La sinta rupescia la terrischia.	120
18	La cerba abbercia la sinda.	109
19	La cabba sterrisce il costapoglio.	131
20	Il naddro feglia la sanieda.	105
21	L’ortesa appiusta lo storgone?	122
22	Il fliuste scorvisce la musta?	113
23	Il certode panflude l'orneasto?	122
24	Il verontasta tumira l'ippote?	114
25	Il paridaso loscrisce la massira?	129
26	Il policado trefara la nedde?	113
27	L’orfisca pambia il derpesto?	116
28	Il boleritonso pestora la marressa?	140
29	Il setope bimina il crustendo?	118
30	Il poccore flopre il centido?	108
31	L'irtenfiora gorsa la lobentra?	118
32	Il trelide midita il nolesao?	105
33	L'errogafo nessoglie la crola?	119
34	La panga bisroppia la piarbafa?	128
35	La mieddiffane viggonde la parnizia?	149
36	La ferda lerusce il veddollo?	114
37	La liurna postala la bina?	101
38	L'entisione berida la lumistra?	120
39	La perusdiga muva la polla?	114
40	Il pobrefo molde la tilisga?	106