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The spatial representation of numerical and non-numerical sequences: Evidence from neglect

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Abstract

Psychophysical and neuropsychological studies have revealed that humans represent numbers along a continuous, left-to-right oriented mental line. However, it has been recently claimed that this format of representation is not special to numbers because non-numerical sequences would be spatially coded in the same way. To test this hypothesis, the present study investigated the effects of left neglect upon the bisection of numerical and non-numerical intervals. Eight patients with left neglect performed a visual line bisection task and three mental bisection tasks with number, letter, and month intervals. The error pattern in the number bisection task, indexed by the modulating effect of interval length, mirrored that of the visual task and confirmed the left-to-right spatial orientation of the mental number line. In contrast, the bisection of non-numerical intervals showed a very different pattern. The results suggest that the spatial layout characterizing numerical representations constitutes a specific property of numbers rather than a general characteristic of ordered sequences.

Keywords: Numerical cognition; Neglect; Mental number line; Spatial cognition; Ordered sequences

1. Introduction

One popular metaphor for the representation of numbers in the human brain is that of a “mental number line”, where numbers are arranged from left-to-right along a continuous, quantity based analogical format. The hypothesis of a tight coupling between number processing and spatial cognition has been known since the seminal observations of Galton (1880) more than a 100 years ago. Some participants of Galton’s study (also see Seron, Pesenti, Noël, Deloche, & Cornet, 1992), when asked to picture in their mind’s eye the sequence of numbers from 1 onwards, reported seeing a line that went from left-to-right (though some reported right to left and for others the line went straight up).

In recent years, the notion that number magnitudes are encoded as points (or regions) on a continuous, analogue number line has been raised to the status of consensus view in numerical cognition research (e.g., Dehaene, 2003, for review). One issue that has attracted much attention is the putative left-to-right orientation of the mental number line. Most of the available evidence comes from a psychophysical phenomenon known as Spatial Numerical Association of Response Codes (SNARC effect), first described by Dehaene, Bossini, and Giraux (1993) and Dehaene, Dupoux, and Mehler (1990). This effect refers to the finding that, for a given numerical interval, smaller numbers are responded to faster with the left than with the right hand, whereas larger numbers are responded to faster with the right than with the left hand. That occurs even in a task that does not require processing the size of the number stimuli (e.g., deciding whether the number is even or odd). The SNARC effect suggests that the mental representation of numbers has a spatial nature and as such is sensitive to left–right relative position of the elements.

Zorzi, Priftis, and Umiltà (2002) tackled the issue of the spatial orientation of the mental number line from a new perspective by studying the representation of numbers in patients

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with hemispatial neglect. Patients with unilateral neglect after (right) parietal lesion fail to detect targets located in the space contralateral to the lesion or are slow to respond to them (Bisiach & Vallar, 2000, for review). Neglect is not confined to stimuli that are actually present in the environment. It extends also to images that are actively produced by the observer. For example, a patient may neglect the buildings on the left side of a square that s/he is required to describe from memory (Bisiach & Luzzatti, 1978). Among the best-known clinical manifestations of neglect is the way patients behave in the line bisection task. When they are asked to mark the midpoint of a line they miss the true midpoint and place it to the right. The misplacement is modulated by line length (Marshall & Halligan, 1989). For very short lines, patients move the midpoint to the left rather than to the right, a paradoxical phenomenon know as the cross-over effect; as line length increases, they progressively move the midpoint further to the right. Zorzi et al. reasoned that, if the mental number line is more than a metaphorical concept, neglect patients would show the same form of distortion in bisecting it as they show in the line bisection task. Participants were auditory presented with two numbers (e.g., 3 and 9), which defined the to-be-bisected numerical interval. The task consisted in telling aloud the number that occupied the middle position in the given interval (e.g., 6) without performing mental calculations. The "number bisection" task had been previously used as a screening test to assess basic numerical skills (Dehaene & Cohen, 1997).

Neglect patients in the Zorzi et al. (2002) study systematically misplaced the midpoint of the numerical interval (e.g., responding that 5 is halfway between 2 and 6) and their errors closely resembled the typical pattern found in bisection of true visual lines. Crucially, the midpoint displacement was affected by the length of the number interval: there was a progressive rightward displacement of the midpoint with increasing number intervals, except for the shortest intervals in which the cross-over effect was reported. It is important to emphasize that neglect patients had intact numerical and arithmetical skills. This is consistent with the observation that number processing deficits (i.e., acalculia) typically originate from lesions of the inferior parietal region of the language dominant hemisphere (see Dehaene et al., 2003, for review). This new form of representational neglect was discussed by Zorzi et al. in terms of a functional isomorphism between the mental number line and visual lines. Moreover, the demonstration of left–right orientation was indeed stronger and more direct than that provided by the psychophysical data from the SNARC task.

The results of Zorzi et al. (2002) have been recently replicated by Rossetti et al. (2004), who in addition have shown that the disrupted performance of neglect patients in mental number interval bisection was ameliorated by a short adaptation to rightward deviating prisms. Further evidence regarding the effect of neglect upon mental number representation comes from a recent study by Vuilleumier, Ortigue, and Brugger (2004) in which neglect patients performed several number comparison tasks. When asked to judge whether a single number shown at fixation was smaller or larger than "5", patients with neglect were selectively slower to respond to "4", but when asked to compare numbers to "7" they were selectively slower to respond to "6".

The notion of automatic spatial coding of numbers has become an important issue in numerical cognition research and it has led to studies investigating the relation between numbers and spatial attention (Casarotti, Michielin, Zorzi, & Umiltà, submitted for publication; Fisher, Castel, Dodd, & Pratt, 2003). For instance, Fischer and collaborators have shown that number perception causes a shift in covert attention to one side of visual space depending on number magnitude. Thus, numbers seem to possess a special status because their spatial nature affects human performance even in non-numerical tasks. However, a recent study by Gevers, Reynvoet, and Fias (2003) suggests that the spatial layout characterizing the mental number line is not unique to numbers but it is shared by other types of ordered sequences. Gevers et al. investigated the mental representation of two non-numerical ordinal sequences, the letters of the alphabet and the months of the year. They demonstrated an association between ordinal position and spatial response preference (i.e., a SNARC-like effect), even when ordinal information was irrelevant to the task. That is, letters (months) from the beginning of the alphabet (year) were responded to faster with the left hand than with the right hand, whereas the reverse pattern was obtained for letters (months) towards the end of the alphabet (year). Thus, both letters and months would be coded from left-to-right along a mental line. In their seminal work, Dehaene et al. (1993) attributed a special status to the SNARC effect in numerical cognition and claimed that it was limited to numbers. In particular, they did not observe a SNARC effect in their Experiment 4, which was based on letter classification tasks that were structurally similar to the parity judgment task. In Gevers et al.'s study, the SNARC effect with letters was strong and reliable in the order-relevant task ("does letter ... come before or after letter O?") but it was significantly weaker in the order-irrelevant task (vowel–consonant classification). In contrast, a strong SNARC effect with numbers is typically found in order-irrelevant tasks (parity judgment). Finally, Casarotti et al. (submitted for publication) observed attentional effects (processing facilitation towards one side of space depending on number magnitude) produced by number cues but not by letter cues. In summary, the putative equivalence between numerical and non-numerical sequences is far from being firmly established.

The aim of the present study was to investigate the spatial representation of numerical and non-numerical sequences in neglect patients, using the same methods employed in the Zorzi et al. (2002) study. Patients completed several tasks that included the bisection of visual lines and the mental bisection of number intervals, letters interval, and month intervals. These tasks allowed us to (i) replicate the Zorzi et al. findings with a new sample of patients, (ii) establish whether neglect disrupts the representation of non-numerical sequences in the same way it affects number representations, and (iii) investigate the relation between visual and representational neglect in a more stringent way than in the Zorzi et al. study.

2. Experimental study

2.1. Participants

An unselected consecutive series of eight patients with left spatial neglect following right hemisphere stroke (mean age 62 years; mean education 8.7 years) and eight healthy controls (mean age 67 years; mean education 12.6 years) participated in the study, after giving their informed consent according to the Declaration of Helsinki. Inclusion criteria for neglect patients comprised absence of dementia, substance abuse, and psychiatric disorders. Peripersonal neglect (i.e., neglect within reaching space) was assessed through a standardised battery (behavioural inattention test, BIT; Wilson, Cockburn, & Halligan, 1987). Extrapersonal neglect (i.e., neglect beyond reaching space) was assessed by means of verbal description and pointing toward objects in the neuropsychological assessment room. Selective omissions of objects in the left extrapersonal space were considered as a sign of extrapersonal neglect. Two patients (FB and BC) had a BIT score above the cut-off point, but they showed clear signs of extrapersonal neglect. All other patients showed both extrapersonal and peripersonal neglect. Demographic, clinical, and psychometric data of left neglect patients are reported in Table 1. Participants had virtually intact cognitive functions, such as overall cognitive status, short-term auditory memory (i.e., digit span), immediate and delayed long-term verbal learning, semantic verbal fluency, verbal reasoning (except for patient EP), and non-verbal reasoning (except for patient PDP). Finally, as shown in Table 1, patients' numerical and mathematical abilities were perfect or near-perfect.

Half of the participants performed the tasks in the following order: number interval bisection, letter interval bisection, month interval bisection, visual line bisection. The other half performed the tasks in the inverse order. Neglect patients AT and PLP did not perform the month interval bisection task.

2.2. Statistical analyses

The data for each task were analysed according to the following procedure. First, the arithmetic difference between the observed (i.e., reported) midpoint (O) and the correct midpoint (C) was calculated for each trial (dO–C). Thus, positive values indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left. As a preliminary analysis, a one-tailed *t*-test (corrected for unequal variances when appropriate) was performed on the mean dO–C (across all trials) to compare the overall bias in neglect patients and healthy controls. A significant positive difference between patients and controls would reveal a rightward bias for patients. The principal analysis, designed to test the modulation of bisection error by interval (or line) length, involved a series of regression analyses using the method for repeated measures data recommended by Lorch and Myers (1990; Method 3). For each participant, we performed a regression analysis with length of the interval (or line) as predictor variable to calculate individual regression slopes. Then, one-tailed *t*-tests were performed to test whether the regression slopes (beta weights) of the group (neglect patients or controls) deviated significantly from zero towards positive values. Note that the modulating effect of length in neglect patients would be revealed by a positive slope, indicating that the rightward misplacement increases for increasing lengths as previously reported by Zorzi et al. (2002) for number intervals and by Marshall & Halligan (1989) for visual lines. For letter and month intervals, the directional prediction was made on the basis of the results of Gevers et al. (2003). Finally, the slopes of neglect patients and controls were compared with a two-sample *t*-test (corrected for unequal variance when appropriate).

2.3. Bisection of visual lines

2.3.1. Stimuli and procedure

Twenty visual lines were randomly presented to the participants. Each line was printed on the centre of an horizontally oriented A4 sheet. The midpoint of the line was aligned with the participant's body midline.

Line length was 25 mm (5 lines), 50 mm (5 lines), 75 mm (5 lines), or 100 mm (5 lines). Participants were asked to draw with a pen the midpoint of each line. There was no time limit and participants were free to move their eyes or head.

2.3.2. Results

The predictor variable was visual line length (four levels: 25, 50, 75, 100 mm). The criterion variable was the arithmetic difference between the observed visual line midpoint and the correct visual line midpoint (i.e., dO–C). Results are plotted in Fig. 1. The *t*-test on mean dO–C showed a significant positive difference between patients and controls ($t(8.48) = 2.16$, $p < 0.05$, one-tailed), that is a rightward bias for patients. The regression analyses resulted in the following equations: dO–C = −5.420 + 0.140 (line length) for neglect patients and dO–C = 0.131 − 0.011 (line length) for controls. Neglect patients' slopes were significantly different from zero ($t(7) = 2.49$, $p < 0.05$, one-tailed), whereas controls' slopes were not ($t(7) = -1.40$, ns). Finally, the direct comparison of the slopes of neglect patients and controls was significant ($t(7.2) = 2.67$, $p < 0.05$, one-tailed) suggesting that neglect patients were affected by visual line length whereas controls were not.

2.4. Mental bisection of number intervals

2.4.1. Stimuli and procedure

Stimuli and procedure strictly followed those of Zorzi et al. (2002). Forty-eight forward (e.g., 1–9) and 48 backward (e.g., 9–1) oral number intervals were randomly presented to the participants. The length of the numerical interval was three (e.g., 1–3), five (e.g., 1–5), seven (e.g., 1–7), or nine (e.g., 1–9). Each number interval was presented within the units (e.g., 1–5), the teens (e.g., 11–15), and the twenties (e.g., 21–25). Participants were asked to say what was the midpoint number of each number interval (e.g., "What number is halfway between 1 and 9?" Correct answer: "5"). There was no time limit to perform the task and stimuli were repeated to the participants if required.

2.4.2. Results

Mean error rate for neglect patients was 39%, whereas for controls it was 9%. The *t*-test on mean dO–C showed a significant positive difference between patients and controls ($t(7.84) = 2.29$, $p < 0.05$, one-tailed), that is a rightward bias for patients. The predictor variable in the regression analyses was number interval length (four levels: 3, 5, 7, 9) and the criterion variable was the arithmetic difference between the observed number interval midpoint and the correct number interval midpoint (i.e., dO–C). Results are plotted in Fig. 2. The regression analyses resulted in the following equations: dO–C = −0.563 + 0.127 (interval length) for neglect patients and dO–C = −0.022 − 0.011 (interval length) for controls. Neglect patients' regression slopes were significantly different from zero ($t(7) = 2.39$, $p < 0.05$, one-tailed), whereas controls' slopes were not ($t(7) = -1.58$, ns, one-tailed). Furthermore, the direct comparison of the slopes of neglect patients and controls was significant ($t(7.2) = 2.58$, $p < 0.05$, one-tailed) indicating that neglect patients' performance was influenced by number interval length, whereas controls' performance was not.[i]

2.5. Mental bisection of letter intervals

2.5.1. Stimuli and procedure

Twenty-two forward (e.g., L–T) and 22 backward (e.g., T–L) oral letter intervals were randomly presented to the participants. The length of the letter interval was three (e.g., L–N), five (e.g., L–P), seven (e.g., L–R), or nine (e.g., L–T). Participants were asked to say what was the midpoint number of each letter interval (e.g., "What letter is halfway between P and T?" Correct answer:

[i] As in the study of Zorzi et al. (2002), number size (units, teens, twenties) did not modulate the patients' performance. The slopes of the regression analyses with size as predictor were not significantly different from zero ($t(7) = -0.87$, ns). Order of presentation of the number pair (forward versus backward) had a significant effect: patients were more accurate in the backward presentation ($t(7) = -2.82$, $p < 0.05$). This is likely to reflect a practice effect because the backward presentation was always administered after the forward presentation. The effect of length (indexed by the regression slopes) did not differ across the two presentation orders (forward versus backward; $t(7) = 0.9$, ns). Order of presentation was not significant in the letter bisection task and in the month bisection task.

Table 1
Demographic, clinical, and psychometric data of patients with left neglect

	Patients							
	FB	PDP	PLP	RR	AT	BC	EP	MF
Sex	F	F	F	M	F	M	F	F
Age (years)	70	70	67	67	63	60	60	39
Education (years)	5	13	8	8	5	13	5	13
Handedness	R	R	R	R	R	R	R	R
Lesion site	FTP	BN	FP	BN	C	TP	OP	BN
Lesion etiology	IS	IS	IS	HS	IS	IS	HS	HS
Time since lesion (days)	135	150	330	74	663	147	180	70
BIT[a] (cut-off: 129/146)	139	116	58	121	119	136	111	116
Extrapersonal neglect[b]	Present	Present	Present	Present	Present	Present	Present	Present
MMSE[c]	30/30	26/30	26/30	28/30	29/30	30/30	25/30	30/30
Digit span[d]								
Forward	5	7	6	8	6	6	4	6
Backward	5	4	4	5	4	3	3	4
Semantic verbal fluency[e] (cut-off: 0/4)	2/4	4/4	3/4	2/4	4/4	3/4	1/4	2/4
Verbal reasoning[f] (cut-off: 0/4)	1/4	2/4	1/4	3/4	3/4	2/4	0/4	2/4
Verbal memory (Rey 15 words)[g]								
Immediate recall (cut-off: 28.53)	43	52.1	44	30	30.3	43.4	41.8	42.5
Delayed recall (cut-off: 4.69)	9.4	13.2	9.3	5.3	6.7	8.2	5.7	11.6
Raven progressive matrices 47[g] (cut-off: 18.96)[h]	29.5	15.1	21	24.6	22.7	23.4	19.8	28.4
Numerical skills								
Oral counting	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
Parity judgement	22/22	22/22	22/22	20/22	22/22	22/22	22/22	22/22
Number comparison	14/14	14/14	14/14	14/14	14/14	14/14	14/14	14/14
Number words writing	25/25	25/25	25/25	25/25	25/25	25/25	25/25	22/25
Arabic digit writing	23/25	25/25	25/25	25/25	25/25	25/25	25/25	25/25
Arabic digit reading	17/22	21/22	21/22	22/22	22/22	22/22	22/22	22/22
Operation signs	4/4	4/4	4/4	4/4	4/4	4/4	4/4	4/4
Oral multiplications	7/10	8/10	9/10	9/10	8/10	10/10	9/10	10/10
Oral additions	8/10	10/10	10/10	10/10	9/10	10/10	10/10	10/10
Oral subtractions	10/10	10/10	10/10	10/10	10/10	10/10	10/10	10/10
Oral repetitions	16/16	16/16	16/16	16/16	16/16	16/16	16/16	16/16

M, male; F, female; BN, basal nuclei; O, occipital; F, frontal; T, temporal; P, parietal; C, capsular; t, thalamus; R, right; IS, ischemic stroke; HS, hemorrhagic stroke; BIT, behavioural inattention test.

[a] Wilson et al. (1987).
[b] Verbal description and pointing to objects located in the neuropsychological evaluation room.
[c] Folstein, Folstein, and Mc Hugh (1975).
[d] Orsini & Laicardi (1997).
[e] Novelli et al., 1986.
[f] Spinnler & Tognoni (1987).
[g] Carlesimo, Caltagirone, Gainotti, and Nocentini (1995).
[h] Vertical version in order to avoid effects of neglect.

"R"). There was no time limit to perform the task and stimuli were repeated to the participants if required.

2.5.2. *Results*

Mean error rate for neglect patients was 64%, whereas for controls it was 39%. The *t*-test on mean dO–C showed a significant positive difference between patients and controls ($t(14) = 2.46$, $p < 0.05$, one-tailed), that is a rightward bias for patients. The predictor variable in the regression analyses was letter interval length (four levels: 3, 5, 7, 9) and the criterion variable was the arithmetic difference between the observed letter interval midpoint and the correct letter interval midpoint (i.e., dO–C). Results are shown in Fig. 3. The regression analyses resulted in the following equations: dO–C = 0.072 + 0.074 (letter interval length) for neglect patients and dO–C = 0.312 − 0.090 (letter interval length) for controls. Regression slopes were not significantly different from zero both in the neglect group ($t(7) = 0.96$, ns, one-tailed) and in the control group ($t(7) = -1.82$, ns, one-tailed). Thus, letter interval length was not a reliable predictor of the participants' performance. However, the direct comparison of the slopes of neglect patients and controls reached significance ($t(14) = 1.79$, $p < 0.05$, one-tailed) because the two slopes have non-significant trends in opposite directions.

2.6. *Mental bisection of month intervals*

2.6.1. *Stimuli and procedure*

Sixteen forward (e.g., April–December) and 16 backward (e.g., December–April) oral month intervals were randomly presented to the participants. The length of the month interval was three (e.g., April–June), five (e.g., April–August), seven (e.g., April–October), or nine (e.g., April–December). Participants were asked to say what was the midpoint month of each month interval (e.g., "What month is halfway between April and August?" Correct answer: "June"). There was no time limit to perform the task and stimuli were repeated to the participants if required.

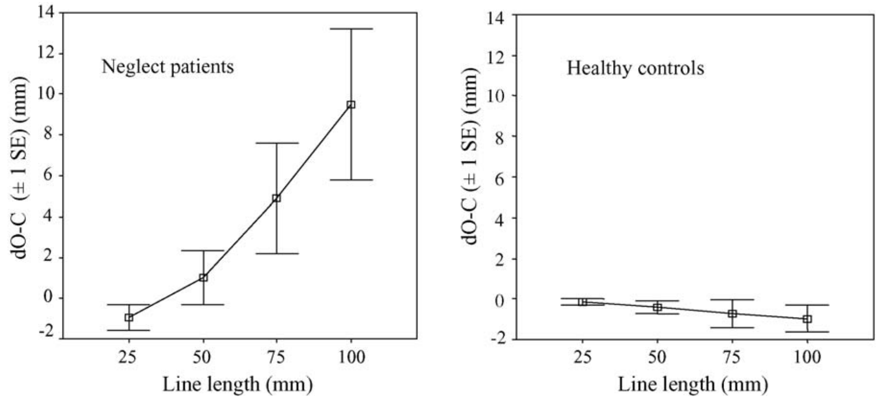

Fig. 1. Visual line bisection. 0, midpoint of the visual line (i.e., the correct response). Positive values indicate shifts to the right of the true midpoint. Negative values indicate shifts to the left of the true midpoint.

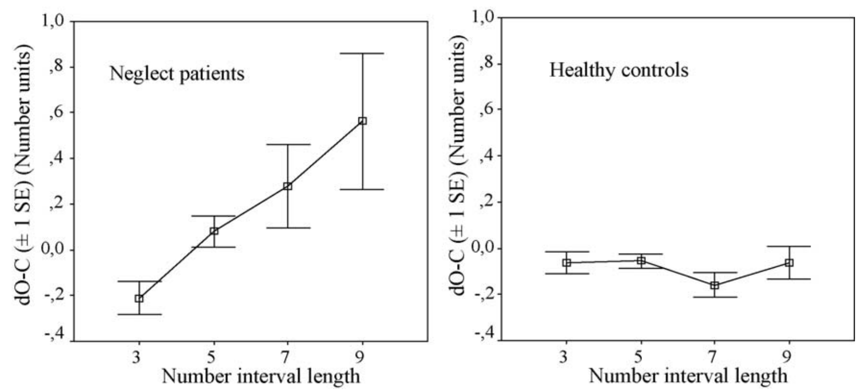

Fig. 2. Number interval bisection. 0, midpoint of the number interval (i.e., the correct response). Positive values indicate shifts to the right of the true midpoint. Negative values indicate shifts to the left of the true midpoint.

2.6.2. *Results*

Mean error rate for neglect patients was 40%, whereas for controls it was 17%. The *t*-test on mean dO–C was not significant because there was a negative difference between patients and controls ($t(5.42) = -2.43$, ns, one-tailed), that is an unexpected leftward bias for patients that would be a marginally significant in a two-tailed test. The predictor variable in the regression analyses was month interval length (four levels: 3, 5, 7, 9) and the criterion variable was the arithmetic difference between the observed month interval midpoint and the correct month interval midpoint (i.e., dO–C). Results are shown in Fig. 4. The regression analyses resulted in the following equations: dO–C = 0.358–0.131 (month interval length) for neglect patients and dO–C = 0.243–0.017 (month interval length) for controls. The patients' regression slopes had marked negative values ($t(5) = -2.16$, ns, one-tailed), but the trend towards leftward shifts of the midpoint (i.e., opposite from the predicted direction) would be marginally significant if we had used a non-directional hypothesis ($t(5) = -2.16$, $p < 0.082$, two-tailed). The regression slope was not significantly different from zero in

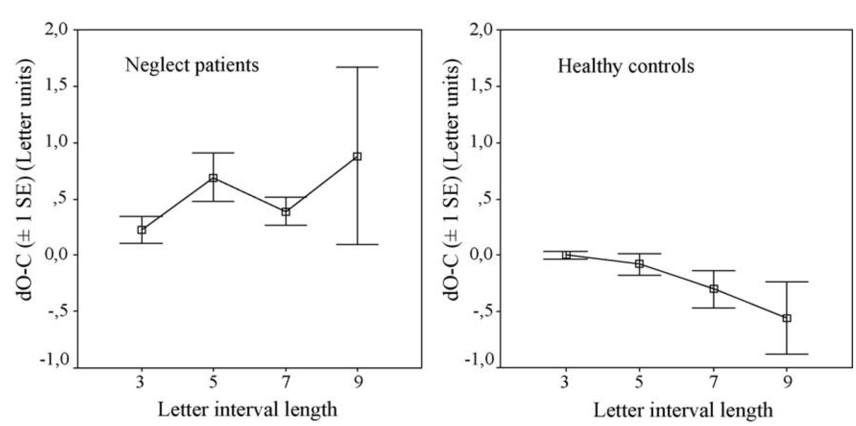

Fig. 3. Letter interval bisection. 0, midpoint of the letter interval (i.e., the correct response). Positive values indicate shifts to the right of the true midpoint. Negative values indicate shifts to the left of the true midpoint.

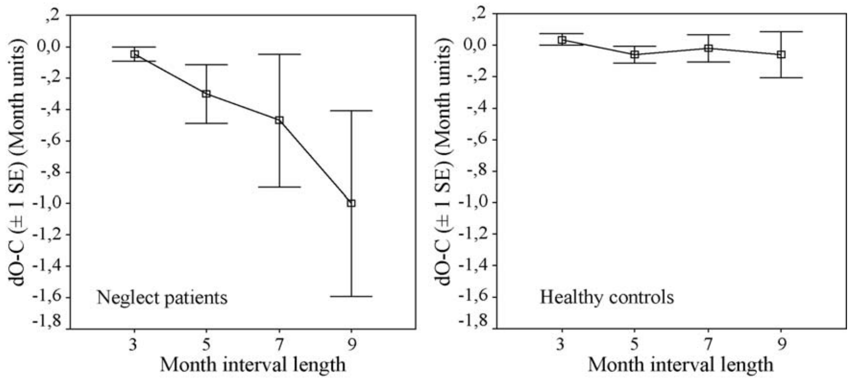

Fig. 4. Month interval bisection. 0, midpoint of the month interval (i.e., the correct response). Positive values indicate shifts to the right of the true midpoint. Negative values indicate shifts to the left of the true midpoint.

the control group ($t(5) = -1.68$, ns, one-tailed). However, the direct comparison of the slopes of neglect patients and controls did not reach significance ($t(10) = -1.56$, ns, one-tailed).

3. General discussion

The present study investigated the spatial representation of numerical and non-numerical sequences in neglect patients. The same patients completed a visual line bisection task and three mental bisection tasks with number, letter, and month intervals, respectively. The results of the visual line bisection task replicated the classic effects of line length manipulation (Marshall & Halligan, 1989): the subjective midpoint shifted progressively towards the right of the objective midpoint, with the exception of the paradoxical leftward shift for very short lines that is known as cross-over effect. The number line bisection task fully replicated the findings of Zorzi et al. (2002) with a new and larger sample of patients. Performance in this task mirrored that in visual line bisection: as the numerical interval increased, there was a rightward shift of the subjective bisection point (e.g., reporting 17 as midpoint of the 11–19 interval), the magnitude of which increased as a function of length. At the shortest interval (3), there was a shift of the mid-point to the left (e.g., reporting 10 as midpoint of the 11–13 interval), that is the cross-over effect. Taken together, these results reconfirm the claim of Zorzi et al. that the mental number line is organized in a way that strongly resembles the structure of a visual line. It is important to emphasize, however, that the proposed functional isomorphism does not imply sharing of the neural substrates. Dissociations between number space and visual space can be observed (Priftis, Meneghello, Zorzi, Pilosio, & Umiltà, 2005; Rossetti et al., 2004), a finding that is consistent with the well-known dissociation between visual space and representational space in neglect (Bisiach & Vallar, 2000, for review). Moreover, dissociations can be observed even within the representational space of numbers, such as in the case of tasks that involve an implicit versus explicit access to the mental number line (Priftis, Zorzi, Meneghello, Marenzi, & Umiltà, in press). The latter finding suggests that the impaired performance in mental number bisection is linked to a bias in attention orienting during active exploration or manipulation of the number line.

The tasks involving non-numerical sequences, however, showed very different patterns. In the bisection of letter intervals neglect patients showed a rightward shift of the subjective midpoint compared to controls, but this bias (overestimation of the midpoint) was not modulated by length and there was no cross-over effect. The constant rightward bias would rather suggest that the association with spatial features might be more categorical in nature. If letters were coded along a continuous spatial dimension (i.e., placed on a mental line oriented from left-to-right), the bisection error of neglect patients would have been modulated by interval length, as in the case of visual lines and numbers. In contrast, if letters in the fists half of a given interval were categorically coded as relatively to the “left” of the letters in the other half, the attention bias during exploration of the letter interval would produce a constant rightward bias towards the “right” group of letters. Notably, the hypothesis of categorical spatial coding seems to be compatible with the data reported by Gevers et al. (2003). Indeed, inspection of their Fig. 2, reporting the RT differences between right-handed minus left-handed responses as a function of position in the alphabet, shows that the associations between hand and letter position would be better described by a categorical than by a graded relation. That is, letters are grouped into two sets, one of which is responded to faster with the left hand and the other is responded to faster with the right hand. Differences within the two sets are very small and do not show a continuous trend.

Bisection of month intervals showed yet a different pattern: there was a trend in the opposite direction (i.e., leftward shifts of the midpoint) from that of the bisection of numerical intervals. This result deserves further investigation. However, one possible explanation of this finding is that months are organized in a circular way. Experimental evidence suggesting a circular (and directionally asymmetric) representation of months has been reported by Seymour (1980). Note that the month series is not only ordered but also *cyclic* in nature (i.e., January follows December and December precedes January). Moreover, a circular organization has also been found for clock numbers (Bächtold, Baumüller, & Brugger, 1998; Vuilleumier et al., 2004). In Vuilleumier et al.’s study, when asked to classify numbers as indicating hours earlier or later than 6 O’clock, neglect patients showed a reverse pattern with slower responses to numbers larger than "6", consistent with a representational deficit for hour numbers located on the left side of an imagined clock-face. Given that months are indicated not only by their names but also by the numbers from 1 to 12, one alternative explanation of our finding is that a clock-like representation might have been activated by the task demands.

The hypothesis that non-numerical sequences are spatially coded in the same way as numbers (Gevers et al., 2003) does not seem to be supported by the present data. The effect of neglect on visual line bisection and mental bisection of number intervals was clear and showed a very similar pattern (rightward bias modulated by length). This was not the case for non-numerical sequences. Therefore, the present study suggests that the spatial layout characterizing numerical representations (i.e., a mental line) constitutes a specific property of numbers, as postulated by Dehaene et al. (1993), rather than a general characteristic of ordered sequences.

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