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Patients With Left Spatial Neglect Also Neglect the "Left Side" of Time

Arnaud Saj[1], Orly Fuhrman[2], Patrik Vuilleumier[1], and Lera Boroditsky[3]
[1]Department of Neurology and Neurosciences, University Hospital of Geneva, University of Geneva; [2]Department of Psychology, Stanford University; and [3]Department of Cognitive Science, University of California, San Diego

Abstract
Previous research suggests that people construct mental time lines to represent and reason about time. However, is the ability to represent space truly necessary for representing events along a mental time line? Our results are the first to demonstrate that deficits in spatial representation (as a function of left hemispatial neglect) also result in deficits in representing events along the mental time line. Specifically, we show that patients with left hemispatial neglect have difficulty representing events that are associated with the past and, thus, fall to the left on the mental time line. These results demonstrate that representations of space and time share neural underpinnings and that representations of time have specific spatial properties (e.g., a left and a right side). Furthermore, it appears that intact spatial representations are necessary for at least some types of temporal representation.

Keywords
spatial memory, time perception

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Time is a fundamental aspect of human experience. What are the cognitive and neural underpinnings of people's representations of time? There are many components of mental time (e.g., temporal order, duration, rhythm, deictic time). In the research reported here, we focused on representations of events along the mental time line. Spatial representations of time (in time lines, clocks, and calendars) are widespread around the world. Languages also rely heavily on spatial words (e.g., *forward, back, ahead, behind*) to talk about the order of events (e.g., Clark, 1973; Lakoff & Johnson, 1980; Traugott, 1978). Previous research suggests people also construct mental time lines to represent and reason about time. Irrelevant spatial information affects people's judgments of temporal order (Boroditsky, 2000; Boroditksy & Gaby, 2010; Boroditsky & Ramscar, 2002; Núñez, Motz, & Teuscher, 2006), and people seem to have implicit associations between parts of space and time (Fuhrman & Boroditsky, 2010; Gevers, Reynvoet, & Fias, 2003; Ishihara, Keller, Rossetti, & Prinz, 2008; Miles, Nind, & Macrae, 2010; Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo, Santiago, & Lupiáñez, 2006; Weger & Pratt, 2008).

However, a key question remains: Are spatial representations truly necessary for representing events in time? In the study reported here, we investigated whether deficits in spatial representation, as caused by left hemispatial neglect following right-brain damage, also result in deficits in representing events along the mental time line. Specifically, we asked whether patients with left hemispatial neglect have difficulty representing events that fall to the left on their mental time line.

Lesions of the right hemisphere, and more specifically of the inferior parietal lobe, commonly give rise to spatial neglect. Patients affected with this syndrome exhibit severe disturbance in the ability to detect, identify, and move toward objects or events in the contralesional (left) side of space, even in the absence of sensory or motor deficits (Driver & Vuilleumier, 2001; Heilman & Valenstein, 1979). In clinical tests, patients show a right-shift bias when asked

Corresponding Author:
Lera Boroditsky, Department of Cognitive Science, University of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0515
E-mail: lera@ucsd.edu

to bisect lines and when performing object-cancellation tasks (Azouvi et al., 2002). In daily activities, patients may leave food uneaten on the left side of their plates, fail to groom the left side of their faces, or miss words on the left side of a printed page when reading (Azouvi et al., 2002). The inability to attend to contralesional space is not limited to the visual modality and can also affect auditory and tactile representations centered around the body or around an object (Driver & Vuilleumier, 2001; Saj & Vuilleumier, 2007; Vuilleumier, 2007).

Furthermore, spatial neglect can be manifested in the inability to generate or adequately maintain a normal representation of the contralesional space. In representational neglect, which is sometimes dissociated from visual neglect, patients have trouble accessing the left side of a mental space when asked to draw objects from memory or retrieve landmarks or locations from the left side of a familiar landscape or map (Bisiach & Luzzatti, 1978; Rode et al., 2010). Representational neglect is also present for conventionally spatialized number arrangements (e.g., numbers as they are represented along the number line or around a clock face; Fischer, 2001; Vuilleumier, Ortigue, & Brugger, 2004; Zorzi, Priftis, & Umiltà, 2002).

If intact spatial representations are indeed necessary for representing events along the mental time line, then patients who show left hemispatial neglect should also neglect the "left side" of time. Previous work has demonstrated that healthy people who read from left to right also represent time as proceeding from left to right, with earlier or past events on the left and later or future events on the right (e.g., Fuhrman & Boroditsky, 2010; Ouellet, Santiago, Israeli, & Gabay, 2010; Tversky, Kugelmass, & Winter, 1991). The left-to-right organization of time has been observed across a wide range of left-to-right reading populations, including francophone participants (e.g., Cienki, 1998), like those included in our study. These observations motivated our prediction that hemispatial neglect might lead to a distortion in the representation of the mental time line. Specifically, patients with left hemispatial neglect who are from cultures that read from left to right should show a selective deficit in representing events as belonging to the past (on the left of the mental time line) as opposed to the future (on the right of the mental time line).

Method

Participants

Twenty-one French-speaking participants were included in this study (7 right-hemisphere stroke patients exhibiting spatial neglect, 7 right-hemisphere stroke patients with no neglect symptoms, and 7 healthy control participants; see Table 1 for demographic information for the

Table 1. Demographic and Clinical Data of Patients

Participant group and patient	Age	Gender	Schooling (years)	Etiology	Line bisection	Bell cancellation			Representational task		Scene copy
						Left	Central	Right	Clock	Flower	
Hemispatial neglect											
Patient 1	83	M	7	H	50.66	6	2	0	3	3	2
Patient 2	69	F	9	H	13.14	15	5	11	3	3	3
Patient 3	72	F	9	H	32.29	5	3	0	2	2	3
Patient 4	81	M	12	I	44.65	15	5	2	1	1	3
Patient 5	57	M	7	I	25.64	15	5	10	3	3	3
Patient 6	60	M	9	H	20.42	12	2	5	2	2	3
Patient 7	75	F	20	I	62.55	13	4	6	2	2	2
No hemispatial neglect											
Patient 1	74	F	12	H	4.20	1	1	0	0	0	0
Patient 2	44	M	22	I	−4.86	2	0	3	0	0	0
Patient 3	82	M	17	I	−3.06	0	1	0	0	0	0
Patient 4	66	M	22	I	−1.21	1	0	1	0	0	0
Patient 5	70	M	7	I	1.82	1	0	0	0	0	0
Patient 6	59	M	12	I	2.20	1	1	1	0	0	0
Patient 7	68	F	9	I	2.13	1	0	1	0	0	0

Note: Line-bisection results are mean errors in percentage of maximal possible errors. Bell-cancellation results are the number of omitted bells in the left, central, and right parts of the test sheet (out of 15, 5, and 15 bells, respectively, in each of these parts). The representational task entailed drawing from memory a clock and a flower; performance was coded from 0 (no omission) to 4 (severe omissions on the contralateral side). The scene-copy task entailed copying a scene that included four distinct elements from the left to the right of the sheet; performance was coded from 0 (no omission) to 4 (severe omissions on the contralateral side). M = male; F = female; H = hemorrhagic; I = ischemic.

patients with and without neglect). Patients had been admitted to the Neurology Department at the University Hospital of Geneva presenting with a first focal right-hemisphere stroke (hemorrhagic or ischemic; see Fig. 1). Neglect was assessed using standard clinical tests (Saj, Verdon, Vocat, & Vuilleumier, 2012; Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010): line bisection (Schenkenberg, Bradford, & Ajax, 1980), bell cancellation (Gauthier, Dehaut, & Joanette, 1989), and scene copy (Gainotti, Messerli, & Tissot, 1972; see Table 1 for clinical test results). None of the patients showed a memory or executive-function deficit. Seven patients presented persistent left hemispatial neglect on repeated testing and were prospectively recruited for the study.

Procedure

All participants completed four blocks of a memory experiment. Each block contained an encoding phase, followed by a recall-test phase and then a recognition-test phase. All participants were tested in French.

Encoding phase. During the encoding phase, participants learned about a fictional man named David. In the first block, participants were told the following:

> Today, David is 40 years old. In the first part of this study, you will learn about things that David liked to eat 10 years ago (when he was 30 years old) and things that he will like to eat in 10 years (when he will be 50 years old).

Participants were further instructed that foods that "David liked to eat 10 years ago" would appear with a picture of a white cap above them (as a cue for younger age), whereas foods that "David will like to eat in 10 years" would appear with a black top hat above them (as a cue for older age).

Participants were then shown line drawings of 10 food items (an egg, corn, a hamburger, spaghetti, ice cream, an apple, grapes, a cake, a sandwich, and a pear), presented one at a time, on a computer screen. Half of the food items had a picture of a white cap above them (indicating the past), and half had a picture of a black top hat above them (indicating the future). Which items were associated with the past and which with the future was counterbalanced across participants. All items (whether associated with the past or the future) were centered along the vertical midline of the screen. For each item, participants were asked to name the food and say whether it was a food that "David liked 10 years ago" or "will like 10 years from now." This procedure was followed for each item. After participants had seen all 10 items, they proceeded to the recall test.

Recall-test phase. In the recall test, participants were asked to freely recall all of the food items mentioned in the encoding phase. For each item they recalled, they further needed to indicate whether it was something "David liked 10 years ago" or "will like 10 years from now." The experimenter wrote down the participants' responses. After participants had listed everything they could recall, they proceeded to the recognition-test phase.

Recognition-test phase. For the recognition test, participants were shown pictures of 14 items (the 10 items from the encoding phase and 4 new items they had not seen before). Pictures were again presented one at a time, centered on the vertical midline of the screen (just

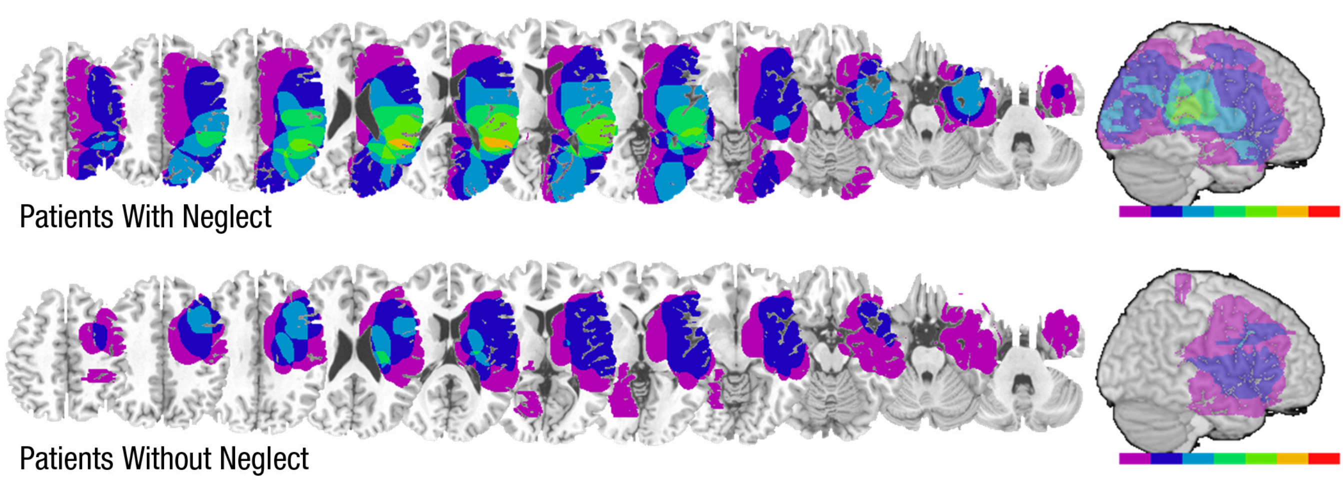

Fig. 1. Areas of lesion overlap across all patients, shown on axial slices of a normalized MRI brain template. The different colors indicate the number of patients with damage to a given area (violet = 1; red = 7). The lateral brain images show that maximum overlap arose in the right temporo-parietal junction.

as in the encoding phase, except that the pictures were shown without hats pictured above them). For each item, participants were asked to indicate whether they had seen the item during the encoding phase. If participants indicated that they had seen the item before, they were then asked whether it was something "David liked 10 years ago" or something he "will like 10 years from now." The experimenter wrote down the participants' responses.

The same procedure (including the encoding phase, the recall phase, and the recognition phase) was then repeated three times with new sets of items. Whereas participants learned about things David liked to eat in Block 1, they learned about things he had in his apartment (a clock, a desk, a kettle, a vase, a telephone, a lamp, a toaster, a refrigerator, a stool, and a television) in Block 2, about things he liked to wear (a shoe, a shirt, pants, a watch, a sock, a tie, a scarf, a boot, a belt, and a coat) in Block 3, and about things he liked to do (sailing, roller-skating, painting, playing football, playing the guitar, reading, flying a kite, playing tennis, skiing, and playing the trumpet) in Block 4.

Results

As predicted, (French-speaking) patients with left hemispatial neglect showed a specific deficit when remembering and attributing items to the past (on the left side of their mental time lines). The main results of interest are shown in Figure 2 (recall memory) and Figure 3 (recognition memory). Results of additional analyses are included in the Supplemental Material available online (Recall Memory: Further Analyses, Recognition Memory: Further Analyses, and Tables S1 and S2).

Recall-memory results

Overall, patients with left hemispatial neglect recalled slightly fewer items (66%) than did patients without neglect (83%) or healthy control participants (78%), but these differences were not significant, $t(12) = 1.61$, $p = .13$, and $t(12) = 1.26$, $p = .23$, respectively. The overall recall rate of patients with neglect also did not differ significantly from that of the two control groups combined,

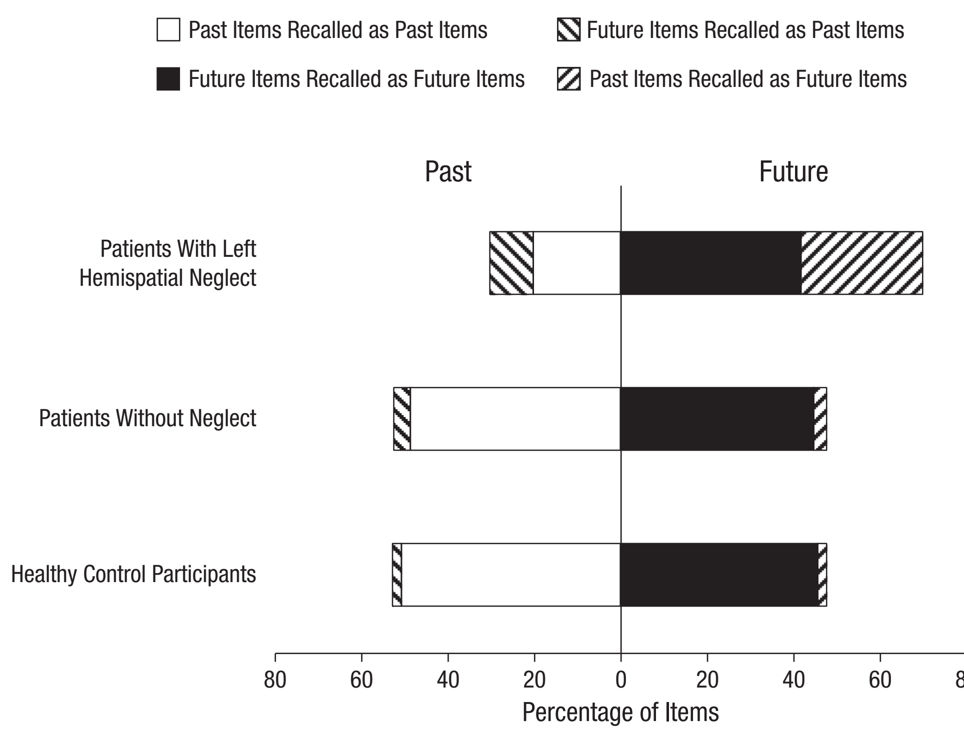

Fig. 2. Results from the recall-test phase. The graph shows the percentage of items recalled as belonging to the past and to the future as a function of participant group. Items fell into four categories: items associated with the future at encoding that were incorrectly recalled as belonging to the past; items associated with the past at encoding that were correctly recalled as belonging to the past; items associated with the future at encoding that were correctly recalled as belonging to the future; and items associated with the past at encoding that were incorrectly recalled as belonging to the future. All "past" responses appear to the left of the midline, and all "future" responses appear to the right of the midline.

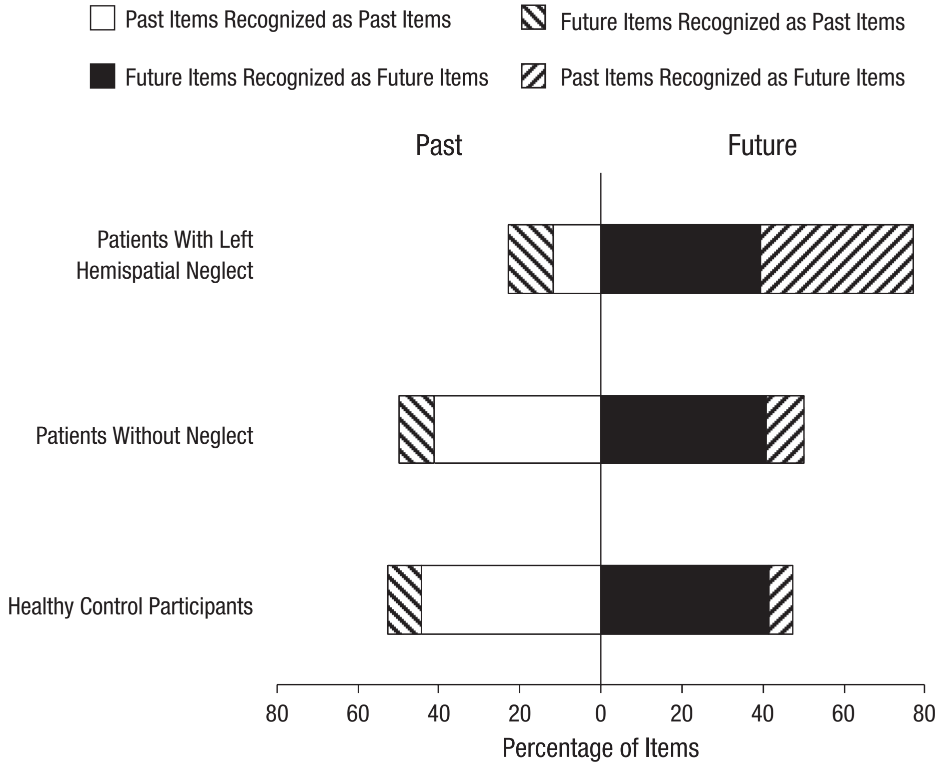

Fig. 3. Results from the recognition-test phase. The graph shows the percentage of recognized items identified as belonging to the past and the future as a function of participant group. Items fell into four categories: items associated with the future at encoding that were incorrectly recognized as belonging to the past; items associated with the past at encoding that were correctly recognized as belonging to the past; items associated with the future at encoding that were correctly recognized as belonging to the future; and items associated with the past at encoding that were incorrectly recognized as belonging to the future. All "past" responses appear to the left of the midline, and all "future" responses appear to the right of the midline.

$t(19) = 1.72$, $p = .10$. Because the data from the two control groups did not differ in any direct comparisons (all $ps > .15$), for brevity, we report results comparing data from the group of patients with neglect with the combined data from the two control groups (we have noted all cases in which results from this combined analysis differed from those of separate analyses).

Planned direct comparisons of the recalled items revealed a pattern of selective deficit for "past" items in patients with neglect. Overall, patients with neglect recalled fewer items that had been associated with the past (64%) than did patients without neglect (85%) or healthy control participants (82%), $t(19) = 2.42$, $p < .05$, $d = 1.11$. Patients with neglect also correctly recalled fewer "past" items as belonging to the past (26%) than did patients without neglect (80%) or healthy control participants (79%), $t(19) = 6.57$, $p < .001$, $d = 3.01$. In contrast, patients with neglect incorrectly recalled more "past" items as belonging to the future (37%) than did patients without neglect (5%) or healthy control participants (3%), $t(19) = 5.96$, $p < .001$, $d = 2.73$.

When it came to items belonging to the future, patients with neglect did not show the same pattern of deficits. Patients with neglect did not recall significantly fewer items that had been associated with the future than did members of the two control groups, $t(19) = 0.96$, $p = .35$, nor were they significantly worse at correctly recalling "future" items as belonging to the future, $t(19) = 1.75$, $p = .10$. Patients with neglect incorrectly recalled slightly more "future" items as belonging to the past (14%) than did patients without neglect (6%) or healthy control participants (3%), $t(19) = 2.96$, $p < .05$, $d = 1.36$; however, this difference was reliable relative only to the healthy control group, $t(12) = 3.02$, $p < .05$, and not to the group of patients without neglect, $t(12) = 1.72$, $p = .11$.

Recognition-memory results

All three groups of participants were accurate in identifying the new items as new (control group = 100% correct, nonneglect group = 99% correct, neglect group = 97% correct), with no differences between groups. For the old items, patients with neglect showed slightly impaired recognition overall (80% correct) relative to patients without neglect (90%), $t(12) = 1.64$, $p = .13$, and healthy control participants (95%), $t(12) = 3.16$, $p < .01$.

Planned direct comparisons of the hit responses (old items that participants identified as old) revealed a pattern of selective deficit for "past" items in patients with neglect. Overall, these patients attributed fewer items to the past (23%) than did patients without neglect (50%), $t(12) = 4.87$, $p < .01$, $d = 2.81$, or healthy control participants (52%), $t(12) = 8.02$, $p < .01$, $d = 4.63$. Patients with neglect also correctly identified fewer "past" items as belonging to the past (19%) than did patients without neglect (74%), $t(12) = 4.96$, $p < .001$, $d = 2.86$, or healthy control participants (84%), $t(12) = 16.02$, $p < .0001$, $d = 9.25$. In addition, again, patients with neglect incorrectly identified more "past" items as belonging to the future (60%) than did patients without neglect (16%), $t(12) = 6.18$, $p < .001$, $d = 3.57$, or healthy control participants (11%), $t(12) = 10.58$, $p < .001$, $d = 6.11$.

In contrast, patients with neglect did not attribute more "future" items to the past (18%) than did participants in the two control groups (16% each; all ps > .65). The two control groups did not differ from one another in any of the direct comparisons (all ps > .2).

Discussion

When reasoning about time, people construct mental time lines according to the spatial schemes afforded by their culture. Our results suggest that an intact ability to represent space is necessary for accurate temporal representation. They demonstrate that a distortion in spatial representation (i.e., unilateral neglect symptoms) predicts a distortion in the way memorized events are represented along the mental time line.

We asked participants to remember a series of events that were associated with either the past or the future. We hypothesized that participants would naturally represent these events on a "mental time map," placing past events to the left and future events to the right in their mind's eye (following the reading and writing directionality of their language, French).

The performance of healthy control participants and patients with no neglect showed symmetrical access to items belonging to the past and to the future. However, patients with neglect recalled fewer items that were associated with the past than did participants in the other groups. Patients with neglect also mislabeled items belonging to the past as "future" items significantly more often than did participants without neglect. This pattern of results suggests that patients with neglect were crowding past events to the right in their mental time map and consequently misattributing past events to the future. This kind of representational crowding is analogous to what has been seen with spatial layouts.

All of the patients with neglect included in our study showed evidence of both perceptual and representational spatial neglect on a standard neurological test battery. It would be interesting for future work to examine the patterns of temporal representation when different types of spatial neglect are dissociated (see Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Saj & Vuilleumier, 2007; Verdon et al., 2010; Vuilleumier, Valenza, Mayer, Réverdin, & Landis, 1998). It would also be interesting to test patients with neglect of right space after left-hemispheric damage, but such symptomatology is rare because of the usual right-hemisphere dominance for spatial processing (Beis et al., 2004).

In addition to the construction of time lines as explored in this article, previous studies that included patients with neglect have demonstrated impaired processing of temporal dynamics; patients have difficulty directing attention in time (Husain, Shapiro, Martin, & Kennard, 1997) and seem to have a distorted estimation of tone durations, especially when the tones are presented in the neglected field—that is, the left ear (e.g., Becchio & Bertone, 2006; Calabria et al., 2011; see also Frassinetti, Magnani, & Oliveri, 2009). Taken together, these data converge to suggest that some neural substrates (e.g., in posterior parietal cortical areas) are shared for the representation of external spatial information and the representation of temporal information (Bueti & Walsh, 2009; Oliveri et al., 2009; Walsh, 2003).

Conclusion

Are spatial representations truly necessary for representing events in time? Our results demonstrate that deficits in spatial representation (as a function of left hemispatial neglect) also result in deficits in representing events along the mental time line. Specifically, our findings show that patients with left hemispatial neglect have difficulty representing events that fall to the left on the mental time line.

Author Contributions

O. Fuhrman and L. Boroditsky developed the study concept. O. Fuhrman spearheaded the study design, with contributions by P. Vuilleumier, A. Saj, and L. Boroditsky. Testing and data collection were performed by A. Saj under the direction of P. Vuilleumier. L. Boroditsky analyzed and interpreted the data, with contributions from A. Saj and O. Fuhrman. L. Boroditsky drafted the manuscript, with critical revisions provided by P. Vuilleumier, A. Saj, and O. Fuhrman. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

References

Azouvi, P., Samuel, C., Louis-Dreyfus, A., Bernati, T., Bartolomeo, P., Beis, J.-M., . . . Rousseaux, M. (2002). Sensitivity of clinical and behavioural tests of spatial neglect after right hemisphere stroke. *Journal of Neurology, Neurosurgery & Psychiatry*, *73*, 160–166.

Becchio, C., & Bertone, C. (2006). Time and neglect: Abnormal temporal dynamics in unilateral spatial neglect. *Neuropsychologia*, *44*, 2775–2782.

Beis, J. M., Keller, C., Morin, N., Bartolomeo, P., Bernati, T., Chokron, S., . . . Azouvi, P. (2004). Right spatial neglect after left hemisphere stroke: Qualitative and quantitative study. *Neurology*, *63*, 1600–1605.

Bisiach, E., & Luzzatti, C. (1978). Unilateral neglect of representational space. *Cortex*, *14*, 129–133.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, *75*, 1–28.

Boroditsky, L., & Gaby, A. (2010). Remembrances of times east: Absolute spatial representations of time in an aboriginal Australian community. *Psychological Science*, *21*, 1635–1639. doi:10.1177/0956797610386621

Boroditsky, L., & Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science*, *13*, 185–189.

Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number and other magnitudes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 1831–1840.

Calabria, M., Jacquin-Courtois, S., Miozzo, A., Rossetti, Y., Padovani, A., Cotelli, M., & Miniussi, C. (2011). Time perception in spatial neglect: A distorted representation? *Neuropsychology*, *25*, 193–200.

Cienki, A. (1998). Metaphoric gestures and some of their relations to verbal metaphoric expressions. In J. P. Koenig (Ed.), *Discourse and cognition* (pp. 189–204). Stanford, CA: CSLI Publications.

Clark, H. (1973). Space, time, semantics, and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27–63). New York, NY: Academic Press.

Doricchi, F., Guariglia, P., Gasparini, M., & Tomaiuolo, F. (2005). Dissociation between physical and mental number line bisection in right hemisphere brain damage. *Nature Neuroscience*, *8*, 1663–1665.

Driver, J., & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition*, *79*, 39–88.

Fischer, M. H. (2001). Cognition in the bisection task. *Trends in Cognitive Sciences*, *5*, 460–462.

Frassinetti, F., Magnani, B., & Oliveri, M. (2009). Prismatic lenses shift time perception. *Psychological Science*, *20*, 949–954.

Fuhrman, O., & Boroditsky, L. (2010). Cross-cultural differences in mental representations of time: Evidence from an implicit nonlinguistic task. *Cognitive Science*, *34*, 1430–1451. doi:10.1111/j.1551-6709.2010.01105.x

Gainotti, G., Messerli, P., & Tissot, R. (1972). Qualitative analysis of unilateral spatial neglect in relation to laterality of cerebral lesions. *Journal of Neurology, Neurosurgery & Psychiatry*, *35*, 545–550.

Gauthier, L., Dehaut, F., & Joanette, Y. (1989). The bells test: A quantitative and qualitative test for visual neglect. *International Journal of Clinical Neuropsychology*, *11*, 49–53.

Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. *Cognition*, *87*, B87–B95.

Heilman, K. M., & Valenstein, E. (1979). Mechanisms underlying hemispatial neglect. *Annals of Neurology*, *5*, 166–170.

Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature*, *385*, 154–156.

Ishihara, M., Keller, P. E., Rossetti, Y., & Prinz, W. (2008). Horizontal spatial representations of time: Evidence for the STEARC effect. *Cortex*, *44*, 454–461.

Lakoff, G., & Johnson, M. (1980). Conceptual metaphor in everyday language. *Journal of Philosophy*, *77*, 453–486.

Miles, L. K., Nind, L. K., & Macrae, C. N. (2010). Moving through time. *Psychological Science*, *21*, 222–223. doi:10.1177/0956797609359333

Núñez, R. E., Motz, B. A., & Teuscher, U. (2006). Time after time: The psychological reality of the ego- and time-reference-point distinction in metaphorical construals of time. *Metaphor and Symbol*, *21*, 133–146.

Oliveri, M., Koch, G., Salerno, S., Torriero, S., Lo Gerfo, E., & Caltagirone, C. (2009). Representation of time intervals in the right posterior parietal cortex: Implications for a mental time line. *NeuroImage*, *46*, 1173–1179.

Ouellet, M., Santiago, J., Israeli, Z., & Gabay, S. (2010). Is the future the right time? *Experimental Psychology*, *57*, 308–314. doi:10.1027/1618-3169/a000036

Rode, G., Cotton, F., Revol, P., Jacquin-Courtois, S., Rossetti, Y., & Bartolomeo, P. (2010). Representation and disconnection in imaginal neglect. *Neuropsychologia*, *48*, 2903–2911.

Saj, A., Verdon, V., Vocat, R., & Vuilleumier, P. (2012). The anatomy underlying acute versus chronic spatial neglect also depends on clinical tests. *Brain*, *135*(2), e207. Retrieved from http://brain.oxfordjournals.org/content/135/2/e207.full

Saj, A., & Vuilleumier, P. (2007). Neglect: Remembering the space left behind. *Current Biology*, *17*, R1060–R1062.

Santiago, J., Lupiáñez, J., Perez, E., & Funes, M. J. (2007). Time (also) flies from left to right. *Psychonomic Bulletin & Review*, *14*, 512–516.

Schenkenberg, T., Bradford, D. C., & Ajax, E. T. (1980). Line bisection and unilateral visual neglect in patients with neurologic impairment. *Neurology*, *30*, 509–517.

Torralbo, A., Santiago, J., & Lupiáñez, J. (2006). Flexible conceptual projection of time onto spatial frames of reference. *Cognitive Science*, *30*, 745–757.

Traugott, E. (1978). On the expression of spatiotemporal relations in language. In J. H. Greenberg (Ed.), *Universals of human language. Vol. 3: Word structure* (pp. 369–400). Stanford, CA: Stanford University Press.

Tversky, B., Kugelmass, S., & Winter, A. (1991). Crosscultural and developmental trends in graphic productions. *Cognitive Psychology*, *23*, 515–557.

Verdon, V., Schwartz, S., Lovblad, K. O., Hauert, C. A., & Vuilleumier, P. (2010). Neuroanatomy of hemispatial neglect and its functional components: A study using voxel-based lesion-symptom mapping. *Brain*, *133*, 880–894.

Vuilleumier, P. (2007). Hemispatial neglect. In O. Godefroy & J. Bogousslavsky (Eds.), *The behavioral and cognitive neurology of stroke* (pp. 148–197). Cambridge, MA: MIT Press.

Vuilleumier, P., Ortigue, S., & Brugger, P. (2004). The number space and neglect. *Cortex*, *40*, 399–410.

Vuilleumier, P., Valenza, N., Mayer, E., Réverdin, A., & Landis, T. (1998). Near and far visual space in unilateral neglect. *Annals of Neurology*, *43*, 406–410.

Walsh, V. (2003). Time: The back-door of perception. *Trends in Cognitive Sciences*, *7*, 335–338.

Weger, U. W., & Pratt, J. (2008). Time flies like an arrow: Space-time compatibility effects suggest the use of a mental time-line. *Psychonomic Bulletin & Review*, *15*, 426–430.

Zorzi, M., Priftis, K., & Umiltà, C. (2002). Brain damage: Neglect disrupts the mental number line. *Nature*, *417*, 138–139.