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RESEARCH ARTICLE

# When a laser pen becomes a stick: remapping of space by tool-use observation in hemispatial neglect

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**Abstract** The role of active tool use in the remapping of space in hemispatial neglect patients has been extensively investigated. To date, however, there is no evidence that observing tool use can play a role in the remapping of space in hemispatial neglect patients. In this study, a patient with a severe hemispatial neglect in near but not far space and twelve healthy controls were asked to bisect near and far lines using a laser pen. The task was performed both before and immediately after sessions in which they merely observed the experimenter bisecting near and far lines with a stick. During the observation session, participants were either holding an identical stick or empty-handed. Results, in both the neglect patient and healthy controls, showed that observing the experimenter bisecting line while holding the same tool, produces a remapping of the far space into the near space. This result was particularly evident in the neglect patient where observing line-bisection task extended the spatial deficit from the near to the far space. Our results provide new empirical support to the idea that the space around us is not mapped in merely metrical terms, rather it seems to be deeply impacted by both action observation and execution.

**Keywords** Neglect · Peripersonal space · Tool-use

## Introduction

Hemispatial neglect is a neuropsychological syndrome typically characterized by a breakdown of spatial awareness following a right hemisphere lesion (Stone et al. 1992). Patients with hemispatial neglect usually fail to orient to and explore the portion of space contralateral to their brain lesion, even in absence of early sensory processing or action execution deficits (Vallar 1998). Dissociations between hemineglect for far (extrapersonal) and near (peripersonal) space (Halligan and Marshall 1991; Cowey et al. 1994; Vuilleumier et al. 1998), as well as

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for extrapersonal and personal space have been described (Bisiach et al. 1986; Guariglia and Antonucci 1992; Peru and Pinna 1997; Marangolo et al. 2003).

There is much evidence that the boundary between peripersonal and extrapersonal space can be modulated by the use of tools, making far space near (Iriki et al. 1996). Several studies on patients with selective neglect for either near or far space have shown that active tool use might either worsen or improve line-bisection performance according to both the spatial location of the line to be bisected (within or out-of-reach) and the kind of tool used (laser pen or stick) (Berti and Frassinetti 2000; Pegna et al. 2001; Ackroyd et al. 2002; Neppi-Mòdona et al. 2007). In particular, Berti and Frassinetti (2000) described the case of a patient (P.P.) who had more severe neglect for near than far space: the neglect for far space worsened when line bisection was executed with a stick that enabled her to actually reach for the lines to be bisected. The same effect was not present when the patient used a laser pen.

Although the role of active tool use in the remapping of space in hemineglect patients has been extensively investigated, to date there is no evidence that observing tool use can play a role in the remapping of space in hemispatial neglect patients. In a previous study, we (Costantini et al. 2011) demonstrated that merely observing tool use, rather than actually using tools, can cause the remapping of space. By taking advantage of a spatial alignment effect, the authors found that observing someone else grasping far objects with a tool such as a garbage clamp extended the near space of the observers just as actually performing (rather than merely observing) this action would have. Interestingly, this effect occurred only when observers held a tool compatible with the goal and spatial range of the observed action.

The present study therefore set out to explore whether and to what extent observing tool use might also impact hemispatial neglect. A patient with severe left hemineglect in near but not far space was required to bisect lines in near and far space. This task was initially performed with a stick that artificially extended the patient's arm, which allowed us to assess the extent to which the patient would extend near space. The patient was then asked to perform the line-bisection task with a laser pen. The line-bisection task with the laser pen was performed both before and immediately after a session in which the patient merely observed the experimenter bisecting near and far lines with a stick while the patient was either holding an identical stick or empty-handed. A group of age-matched healthy subjects was asked to perform the same task in the same conditions.

If observing someone else using a tool closely resembles actually using the tool oneself, we would expect that the patient's observing the experimenter bisecting lines with a tool such as a stick would impact on his performance in the line-bisection task with a laser pen by extending the severity of his hemispatial neglect from near to far space, and that it would do so in the same way as his actually bisecting the lines with the stick himself would. In other words, we would expect that the patient would bisect far lines as if using a stick despite actually using a laser pen. In line with our previous study (Costantini et al. 2011), we would also expect this remapping of space to occur only when the patient observed the experimenter using a tool while holding the same tool as the experimenter.

## Materials and methods

### Participants

A right brain damaged patient (S.B.) and a control group of 12 healthy subjects (three male; mean age 68 years; SD 7 years) gave their informed consent to participate in the study, which was approved by the Ethics Committee of the "Alma Mater Studiorum" University, Bologna. All procedures were in agreement with the 1975 Helsinki Declaration.

S.B. was a 73-year-old, right-handed man when he suffered a right ischemic CVA on October 2010. On admission, he showed severe left hemiparesis, left body anesthesia, and severe left peripersonal and extrapersonal neglect at clinic observation. He was mildly anosognosic for the hemiplegia and severely anosognosic for the visual neglect (Bisiach questionnaire, Bisiach et al. 1986). He was oriented in time and space, and his general reasoning capacities were within the normal range.

A neuropsychological assessment was conducted 2 months after stroke, when he was able to collaborate with the experimenter. The conventional subtests of the Behavioural Inattention Scale (BIT-C, Wilson et al. 1987) confirmed severe neglect for the peripersonal space (score 18/146; cut off >129). In the line cancelation task (Albert 1973), the patient omitted all stimuli depicted on the left side and most of the leftmost stimuli on the right side of the A4 paper (difference between left and right detected stimuli = 10; cut off <1). His figure and shape copying produced drawings that were unrecognizable because lacking detail on the left side (the patient is a non professional painter). Finally, he showed severe disabilities in all activities of daily living on the Bergego scale Bergego et al. 1995) (score 22/30).[1] The patient had no personal neglect (Zoccolotti Object use task, Zoccolotti et al. 1992). This neuropsychological assessment was conducted the day before the experimental sessions.

[1] CBS = Catherine Bergego Scale; A total score of 0 is considered to indicate no neglect, a score ranging from 1 to 10 indicates mild behavioral neglect, a score of 11–20 indicates moderate neglect and a score of 21–30 indicates severe neglect.

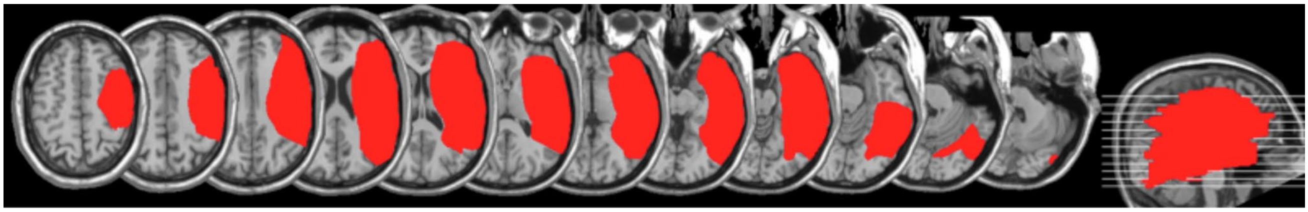

**Fig. 1** The patient had a right occipito-temporo-parieto-frontal lesion involving: inferior occipital gyrus, inferior, middle and superior temporal gyrus, insula, inferior parietal gyrus, angular gyrus and supramarginal gyrus, orbital, inferior and middle frontal gyrus, precentral and postcentral gyrus, internal and external capsule, pallidum, putamen, and occipito-temporo-parieto-frontal periventricular white matter

The MRI digitalized image of patient S.B.'s lesion was mapped using MRIcro software (available at http://www.cabiatl.com/mricro, Rorden C.). The patient's visible lesion on MRI scan was manually traced onto corresponding regions of a normal reference brain (template). As described in detail in Fig. 1, the patient had a right occipito-temporo-parieto-frontal lesion.

## Procedure

Patient and control subjects were tested on a line-bisection task. Lines were presented one at a time, centered on a light-blue opaque plastic support (50 × 70 cm) and aligned with the subject's midline. The plastic support was located on an easel. The easel's height was adjusted to align each line with participants' eye-level. Lines could be presented either at a distance of 60 cm (near space) or at a distance of 180 cm (far space). The lines' lengths were 22 cm in the near space and 66 cm in the far space so that the visual angle subtended by lines was constant across distances (25.28°).

Patient and control subjects sat in front of the support and were required to bisect lines using a tool, keeping their right hands close to the midlines of their bodies. The bisection line task was delivered in four different conditions. The first two conditions consisted in mere line bisections performed with two different tools while in the last two conditions the line-bisection task was performed with the same tool but after an observation session (which differed between the two conditions). In more detail, the patient and control subjects were first required to bisect lines, in near and far space, using a laser pen (hereafter Laser-Pen-Use condition); this does not usually impact on bisection line tasks (see Berti and Frassinetti 2000; Pegna et al. 2001; Ackroyd et al. 2002; Neppi-Mòdona et al. 2007) even if it can determine a compression of perceived distance (Davoli et al. 2012). They were then required to perform the same line-bisection task using a stick, which extended the arm reaching (Stick-Use condition). The length of the stick was adjustable and could be extended from 60 to 180 cm to bisect both near and far lines. The stick was made of aluminum and weighed 100 g. Finally, the participants and the control subjects were required to bisect lines in near and far space with a laser pen after observing the experimenter performing the same bisection task with a stick. The experimenter sat next to the participants, on the their right, and the patient and control subjects were simply required to observe her movements for 5 min, during which 20 line bisections were performed, 10 in near space and 10 in far space, respectively. There were two different observational sessions: participants observed the experimenter's line bisections either holding in their right hands a stick identical to that used by the experimenter herself or being empty-handed. Thus, patient and control subjects performed the line-bisection task with the laser pen after either a with-stick observation session (Post-Observation-with-Stick condition) or an empty-handed observation session (Post-Observation-without-Stick condition). The Post-Observation-without-Stick condition was tested after the Post-Observation-with-Stick condition in the case of the patient, while in the control group the order of presentation of these two conditions was randomized. Each subject provided us with 8 bisection trials per condition. The whole testing procedure lasted roughly 50 min.

## Results

Displacement errors were measured in millimeters and expressed as percentage of the length of the line. Displacement of the subjective midpoint to the right of the objective midpoint of the line (i.e., line-bisection error) is indicated with the sign "+", whereas the sign "−" indicates leftward displacement.

### Controls

To characterize control subjects' performance, a 4 × 2-repeated measures ANOVA was performed on

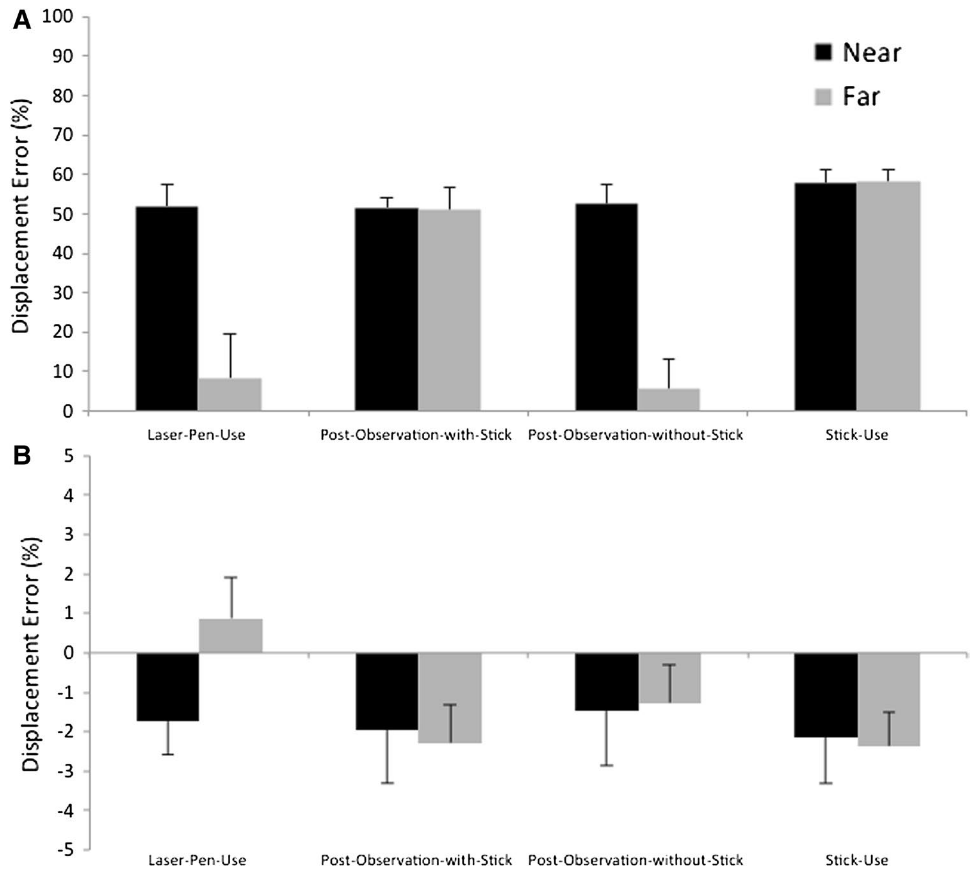


**Fig. 2** Percentage of rightward displacement in the bisection task. *Error bars* indicate standard error of means. **a** Neglect patient. **b** Healthy controls

line-bisection errors with Condition and Space as within-subject variables. The analysis revealed a significant main effect of Condition [$F(3, 33) = 3.24$; $p = .03$; $\eta_p^2 = 0.23$] and a significant Condition by Space interaction [$F(3, 33) = 2.87$; $p = .05$; $\eta_p^2 = 0.21$]. Post hoc analysis of the interaction (Tukey's test) showed no difference in near space among the four experimental conditions (see Fig. 2, *p*s > .75), whereas in far space participants' performance was significantly different between Laser-Pen-Use (0.9 %) and Post-Observation-with-Stick (−2.3 %, $p < .01$) and Stick-Use conditions (−2.4 %, $p < .01$). Laser-Pen-Use condition (0.9 %) did not differ from Post-Observation-without-Stick (−1.3 %, $p > .05$).

*Patient*

Figure 2 shows the patient's line-bisection errors as a function of space in the four conditions. The patient constantly showed a strong (>50 %) rightward bias in the near space regardless of the condition, confirming the severity of his neglect for peripersonal space [Laser-Pen-Use: 51.99 % (95 CI 41.04–62.94 %); Stick-Use: 57.77 % (95 % CI 50.87–64.66); Post-Observation-with-Stick: 51.65 % (95 % CI 41.73–61.56); Post-Observation-without-Stick: 52.50 % (95 % CI 47.42–57.58)].[2]

By contrast, in the far space, the patient's bisection errors were descriptively different across the four conditions. In particular, in the Laser-Pen-Use condition, the patient showed less severe neglect, with a very low rightward bias in bisecting the far line [8.39 % (95 % CI −13.46 to 30.24)]. Note that the 95 % CIs (1) comprised the 0 value, thus suggesting that the patient's neglect may be absent at all for extrapersonal space; (2) did not overlap with those in

[2] Since confidence intervals rely heavily on the central limit theorem, their estimation may be problematic when the sample data are not normally distributed and/or contain extreme values. This could be problematic in our case, as patients' behavior tends to be variable, and because there were only eight observations for each condition. Therefore, to assess the accuracy of the reported confidence intervals, we also performed a bootstrap analysis (bias-corrected and accelerated method, 1,000,000 iterations), which provide a robust estimate of the uncertainty associated with parameter estimates (e.g., Carpenter and Bithell 2000) Bootstrap confidence intervals: when, which, what? A practical guide for medical statisticians. Stat Med 19:1141–1164). The so calculated bias-corrected and accelerated 95 % CIs for each condition were very similar to those reported, suggesting that our estimates were not biased, and led to the same conclusions.

the corresponding conditions in near space, thus suggesting a dissociation between peripersonal and extrapersonal space. A similar pattern of bisection errors emerged in the Post-Observation-without-Stick condition [5.68 % (95 % CI −8.83 to 20.19)]. By contrast, the patient's performance in the Stick-Use condition in far space [58.26 % (95 % CI 52.35–64.17)] was descriptively similar to those showed in near space. This suggests that patient's neglect for far space worsened when line bisection was executed with a tool that enabled him to actually reach for the lines to be bisected. Crucially, a similar pattern of bisection errors emerged in the Post-Observation-with-Stick condition [50.95 % (95 % CI 41.73–62.41)], when the patient was bisecting far lines with a laser pen just after observing the experimenter's line bisections while holding a stick identical to that used by the experimenter herself.

*Patient-controls comparisons*

In order to validate the findings described in the previous section, we contrasted the patient's line-bisection errors with the controls' by carrying out modified *t* tests that estimate the abnormality of the patient's performance taking into account the size of the control group. In particular, we used a program created ad hoc to test whether a single case meets criteria for a dissociation based on the application of classical statistical methods (Dissocs_ES.exe, Crawford et al. 2010).

We first assessed whether the case's scores meet the criterion for a deficit on each condition using the Crawford and Howell's (1998) modified *t* test. The statistics provided for each significance test are a *t* value and the corresponding *p* value, a point estimate of the effect size for the difference between the case and controls (Z-CC), and an accompanying 95 % CI of the Z-CC (see Table 1). The patient showed a significant rightward displacement compared to controls in all conditions in the near space ($p < .0001$ for all comparisons). In far space, patient's performance was significantly different from controls' performance in Stick-Use and in Post-Observation-with-Stick conditions ($p < .0001$ for both comparisons), whereas no statistically significant differences were found between patients and controls in Laser-Pen-Use ($p = .066$) and in Post-Observation-without-Stick conditions ($p = .072$) (see Table 1). These data confirm that the patient showed a severe neglect in the far space similar to that he showed in near space in both Stick-Use and Post-Observation-with-Stick conditions. This effect was absent in both Laser-Pen-Use and Post-Observation-without-Stick conditions.

We then applied the Revised Standardized Difference Test (RSDT, Crawford and Garthwaite 2005) to the difference between the case's scores on two conditions of interest. In this case, for each contrast comparing the case's difference in the two conditions to that of controls, the statistics provided are a *t* value and the corresponding *p* value, a point estimate of the effect size for this effect (Z-DCC), and a 95 % interval estimate of this effect size computed using Bayesian methods with a large number (1,000,000) of iterations (Bayesian Credible Interval: BCI). Moreover, the criteria for dissociation are applied using the results of the foregoing tests. To meet the criteria for a dissociation, the *p* value for the test on the difference between the case's scores (i.e., the RSDT) must be below 0.05 and the *p* value for at least one of the tests for a deficit on the two conditions must also be below 0.05. If the case's scores on both tasks qualify as deficits then the case is classified as exhibiting a "strong dissociation".

**Table 1** Statistics for the patient-controls comparisons

| | *t* | *p* | Z-CC | 95 % CI |
|---|---|---|---|---|
| Laser-Pen-Use | | | | |
| Near | 17.20 | <.0001 | 17.91 | 10.52–25.30 |
| Far | 2.04 | 0.066 | 2.12 | 1.07–3.15 |
| Stick-Use | | | | |
| Near | 14.11 | <.0001 | 14.68 | 8.62–20.75 |
| Far | 20.03 | <.0001 | 20.85 | 12.26–29.45 |
| Post-Observation-with-Stick | | | | |
| Near | 10.66 | <.0001 | 11.09 | 6.49–15.69 |
| Far | 15.60 | <.0001 | 16.24 | 9.54–22.94 |
| Post-Observation-without-Stick | | | | |
| Near | 10.96 | <.0001 | 11.41 | 6.68–16.14 |
| Far | 1.99 | 0.072 | 2.07 | 1.03–3.08 |

Z-CC represents the point estimate of the effect size for the difference between the patient and controls. 95 % CI represents the confidence interval of the Z-CC measure

In order to test for the existence of a patient's dissociation between neglect for near and far spaces, we applied the RSDT to compare the difference between the patient's performance in near space and far space to the corresponding difference in control participants, separately for each of the four task conditions. This analysis confirmed that the patient fulfilled the criteria for a dissociation between near and far space in the Laser-Pen-Use [$t(11) = 10.78$, $p < .001$, Z-DCC = 14.2, Z-DCC 95 % BCI 7.42–22.64] and Post-Observation-without-Stick conditions [$t(11) = 8.08$, $p < .001$, Z-DCC = 10.31, Z-DCC 95 % BCI 5.33–16.38]. The results found in the Stick-Use [$t(11) = 3.91$, $p = .002$, Z-DCC = −4.33, Z-DCC 95 % BCI −12.40 to 2.81] and Post-Observation-with-Stick conditions [$t(11) = 4.35$, $p = .001$, Z-DCC = −5.03, Z-DCC 95 % BCI −12.61 to 1.76] suggested that the near versus far space dissociation was mitigated both when patient used a tool physically extending his reaching space such a stick and also when he used a laser pen after the observation of the experimenter using a stick to bisect near and far lines while holding the same tool. Indeed, even though both the RSDTs were significant, it should be noted that the 95 % BCI of the effect size included the zero value, thus indicating that there is no support for the existence of a clear dissociation between near and far space in the Stick-Use and Post-Observation-with-Stick conditions (Cumming 2013). Moreover, it should also be noted that the Z-DCC effect size in these two conditions had signs opposite those in the Laser-Pen-Use and Post-Observation-without-Stick conditions, indicating that that the patient's performance in far space worsened both when he bisected lines with a stick and when he did it with a laser pen after the observation of the experimenter's line bisections while holding an identical stick in his right hand.

In order to test the reliability of the patient's remapping of space due to the actual use of a tool physically extending the arm reach, we applied the RSDT to compare the difference between the patient's performance in the Laser-Pen-Use and Stick-Use conditions for the far space to the corresponding difference in control participants. In particular, with this analysis, we aimed to assess whether the patient's performance in far space significantly worsened, compared to controls, when he bisected lines with a tool that enabled him to actually reach for the lines to be bisected. The analysis confirmed that remapping of space occurred in the patient after the actual use of the stick [$t$ (11) = 12.90, $p < .001$, Z-DCC = −18.61, Z-DCC 95 % BCI −29.26 to −10]. Moreover, a similar RSDT performed to the difference between Laser-Pen-Use and Post-Observation-with-Stick conditions for the far space confirmed that a similar remapping of space (and the corresponding worsening of the line-bisection performance) also occurred when the patient observed the experimenter bisecting lines with a stick while holding the same tool in his right hand [$t(11) = 10.37$, $p < .001$, Z-DCC = −13.80, Z-DCC 95 % BCI −21.91 to 7.24]. We then assessed whether the patient's space remapping effect in the Post-Observation-with-Stick condition was just due to the observation of the experimenter's line bisections. To this aim, we carried out a RSDT comparing the difference between the patient's performance in the Post-Observation-with-Stick and Post-Observation-without-Stick conditions for the far space to the corresponding difference in control participants. This analysis revealed that the patient's difference between these two condition was significantly higher than the controls' one [$t(11) = 15.2$, $p < .001$, Z-DCC = −26.67, Z-DCC 95 % BCI −40 to −17.75], suggesting that during observation of tool use, the observer has to be in a position to perform the observed action for the space remapping effect to occur.

Finally, in order to assess whether the mere observation of someone else using a tool physically extending their reach had an impact on the patient's performance, we applied the RSDT to compare the difference between the patient's performance in the Laser-Pen-Use and Post-Observation-without-Stick conditions for the far space to the corresponding difference in control participants. The analysis revealed that the difference between these two conditions was virtually the same in both control subjects and the patient [$t(11) = .05$, $p = .963$, Z-DCC = .053, Z-DCC 95 % BCI −1.15 to 1.26], thus suggesting that the mere observation of tool use (that is, observation without holding a tool like that being used) did not influence the line-bisection performance of our participants.

## Discussion

We investigated how both using a tool and observing someone else using a tool might impact on hemispatial neglect by taking advantage of a line-bisection task. Patient and control subjects bisected near and far lines either with a laser pen (Laser-Pen-Use condition) or with a stick (Stick-Use condition). The bisection task with the laser pen was also carried out immediately after observational sessions in which the patient and the control subjects just observed the experimenter bisecting lines with a stick while either holding an identical stick (Post-Observation-with-Stick condition) or else empty-handed (Post-Observation-with-Stick condition).

The results showed that the Laser-Pen Use and Stick-Use conditions affected the patient's performance in the line-bisection task differently. In the Laser-Pen-Use condition, the patient showed a severe neglect in near space only, whereas his neglect was severe in both the near and far spaces in the Stick-Use condition. Indeed, the difference between the displacement errors in the line-bisection task performed in near and far space disappeared when the patient used a stick rather than a leaser pen. Interestingly, the same effect occurred in the Post-Observation-with-Stick condition, but not in the Post-Observation-without-Stick condition, that is, when the patient bisected near and far lines with a laser pen just after observing the experimenter's line bisections while holding in his hand a stick identical to that used by the experimenter. Finally, note that a similar pattern was found in the control subjects.

Possibly one may argue that our results are inconsistent with the findings by Davoli et al. (2012). They found that participants who illuminated targets with a laser pointer consistently judged the targets to be closer than those who pointed at the targets with a baton. According to the authors, these findings indicate that remote interactions can have the same perceptual consequences as physical interactions. Without denying the relevance of their results, it is worth noting that Davoli et al's experiments differ from our study not only with respect to the task (perceived distance vs. bisection), but also with respect to the physical distances involved in the two tasks. Davoli et al. investigated the impact of the laser pointer on the perceived distance when the target was placed at 8 different locations: 1.8, 5.2, 8.8, 13.4, 19.2, 22.6, 26.2, or 30.5 m away from the observer—that is, at physical distances that are not directly comparable with the physical distances employed (60 and 180 cm) in the current study.

Our findings are rather consistent with a body of evidence showing that using a tool which physically extends reach might cause a remapping of space in both healthy (Maravita et al. 2002; Serino et al. 2007) and brain damaged subjects (Berti and Frassinetti 2000; Pegna et al. 2001; Ackroyd et al. 2002; Neppi-Mòdona et al. 2007). Line-bisection studies on patients with selective neglect for the hemispace near to or far from their bodies indicate that using a tool such as a stick might cause remapping far space as near space, thus diminishing or worsening the impact of neglect (Berti and Frassinetti 2000; Pegna et al. 2001; Ackroyd et al. 2002; Neppi-Mòdona et al. 2007). In addition, studies on patients with visuo-tactile extinction (Bueti et al. 2004; Costantini et al. 2007) selectively confined to the space close to one hand show that the severity of extinction can be modified by the active use of a tool that may extend the physical reach of hand actions (Farnè and Ladavas 2000; Maravita et al. 2001). This effect is closely related to the functionally effective length of the tool (Farnè et al. 2005).

Taken together, these and our findings suggest that not only using a tool, but also observing someone else using one, might involve a remapping of space. Observation of the experimenter using a stick to bisect otherwise out-of-reach lines involved remapping far space as near space, thus extending the patient's neglect from the former to the latter.

How could this effect be explained? Why is observation in some ways comparable to actually using a tool? A possible candidate for explaining the observation effect is likely to be found in the action execution/action observation matching properties of the mirror mechanism (Rizzolatti et al. 2001). There is plenty of evidence in monkeys and humans that observing others' actions recruits in the observer's brain the same motor resources and representations that would enable her to perform those actions. This recruitment has been shown to run at different levels of generality, ranging from mirroring kinematic features to mirroring goals (for a review, see Rizzolatti and Sinigaglia 2010), and to occur for both bodily and tool-using actions (Rochat et al. 2010). Furthermore, several studies have demonstrated that observing another's action affects the execution of one's own action according to the degree of congruence between the observed and executed actions (Castiello et al. 2002; Edwards et al. 2003; Kilner et al. 2003).

This may account for the occurrence of spatial remapping after observing the experimenter bisecting lines with a stick. It is worth noting that our patient's neglect for far space worsened when he was required to bisect far lines with a stick rather than a laser pen. Observing the experimenter bisecting lines with the stick recruited the same motor representations that would have been recruited if the patient performed the bisection task with the stick himself. This may explain why the patient's performance in bisecting far lines after the observation of experimenter's line bisections was dramatically worse. As in the Laser-Pen-Use condition, the patient still bisected the lines with a laser pen. But unlike from the Laser-Pen-Use condition, the patient bisected the lines as if he had a stick in his hand rather than a laser pen.

We have already mentioned that this effect occurred only when the patient, in observing the experimenter's line bisections, held the same tool (i.e., the stick) as the experimenter in his hand. How can this constraint be explained? One might hypothesize that tool-use observation did not play a crucial role in the remapping of the patient's space and that, instead, the remapping was primarily due merely to his holding a stick in his hand. However, several studies using a variety of techniques including single cell recording from macaque's brain (Iriki et al. 1996), behavioral studies on both healthy (Witt et al. 2005; Costantini et al. 2011) and brain damaged patients (Farnè and Ladavas 2000; Farnè et al. 2005) demonstrate that merely holding a tool does not usually involve any spatial remapping.

An alternative hypothesis is that, although it is likely that both Post-Observation-with-Tool and Post-Observation-without-Tool conditions led to the recruitment of motor representations of the observed action, these motor representations could actually impact on the patient's performance only when he was in a position to perform the action with a tool like the one he observed. This hypothesis is indirectly supported by a study with healthy subjects showing that observing tool use—so not only actually using tools—can extend subjects' sensitivity to objects' affording features from near to far space, provided that the observer holds a tool compatible with the goal and the spatial range of the observed action (Costantini et al. 2011). The hypothesis is also consistent with previous evidence indicating that an observer's behavior is affected by others' action to the extent that the observer is in a position to perform the same action (Costantini et al. 2011, 2012; Ambrosini et al. 2012).

It is worth noting, however, that Bloesch et al. (2012) reported effects of observation where participants were not holding a tool similar to that being used in the observed action. In particular, these researchers investigated the effect of tool-use observation on visual judgments of distance when the target was located beyond reach of participant arm's (ranging from 75 to 105 cm), and participants without holding any tool in their hands, were asked to observe an actor pointing toward it either with her index finger or with a stick. The result showed that participants judged targets to be closer after watching the actor reach with the stick than after watching the actor reach with her index finger.

How can this apparent discrepancy be explained? Although more research is needed, one possible explanation concerns the different demands, which are supposed to be required to perform the tasks. In particular, it is possible that the remapping of space triggered by watching someone else using a tool should satisfy different constraints according to different tasks. In Bloesch et al. (2012), participants observed either arm or tool pointing actions and then were asked to visually estimate the distance of the targets without acting upon it. In our case, the patient and control subjects observed the same actions (line bisections) they should perform afterward, even if with a different tool. This could explain why, differently from Bloesch et al. (2012), we found a tool-similarity constraint. This could also explain why, differently from Bloesch et al. (2012), Costantini et al. (2011) reported an analogous tool-similarity constraint in a distance visual estimation task, where participants should reproduce the distance of an object targeted in a previous motor task they have either actually performed or just observed being performed by someone else.

In conclusion, our findings indicate that merely observing someone else using a tool such as a stick may cause the remapping of space much as actually using that tool would. This remapping can be so powerful as to affect the observer's subsequent actions, even when these subsequent actions involve using only a tool such as a laser pen that does not physically extend the range of the action.

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