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Mental time-line distortion in right brain damaged patients: evidence from a dynamic spatio-temporal task

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Abstract

Objective: Time is an elusive phenomenon that is difficult to grasp with our senses. Recent work has shown how spatial representations often lie beneath temporal ones as shown by a family of spatiotemporal congruency effects. For instance, individuals who have been exposed to left-to-right orthographic systems are better at judging short durations with their left effector, and long durations with their right effector, than vice versa, a phenomenon known as the STEARC effect. In the present neuropsychological study, we aimed to provide evidence that spatial attention mechanisms play a crucial role in generating this spatially organized mental time line. Method: A group of 13 patients suffering from right hemisphere lesions with different degrees of spatial neglect signs and a control group of 15 age- and education-matched neurologically healthy participants were administered a unimanual version of a spatiotemporal compatibility task (STEARC task). Results: The main results showed that the more a patient suffered from spatial neglect signs, the smaller the accuracy difference between left and right side responses for short durations was. Conclusions: These findings corroborate the hypothesis that the presence of disorders in spatial-attention affects the left-to-right mental time line representation, especially in its leftward segment, proportionally with the amount of deficit. This study therefore suggests the critical role of spatial attention for the emergence of a spatial representation of time durations.

Keywords: STEARC effect; time processing; spatial attention; neglect; spatial compatibility effects.

Introduction

We do not have a sense devoted to time perception. However, representing temporal events is indubitably a critical skill for interacting with our internal and external world. Different studies have shown that the temporal processing is tightly linked with spatial representations and, more specifically, with spatial attention, through a partially overlapping neural substrate (e.g., Coull & Nobre, 1998) and though experiential influences (see Bonato, Zorzi, & Umiltà, 2012; and Oliveri, Koch, & Caltagirone, 2009, for reviews). Spatial attention and spatial representations can bias time processing in several ways (e.g., Santangelo & Spence, 2009; Santiago, Lupiáñez, Pérez, & Funes, 2007; Torralbo, Santiago, & Lupiáñez, 2006; Vicario, Rappo, Pepi, & Oliveri, 2009), while the opposite influence of time processing over spatial representations does not necessarily occur (Boroditsky, 2000; Casasanto & Boroditsky, 2008). This asymmetry can already be documented at about 4-5 years of age (e.g., Bottini & Casasanto, 2013; Casasanto, Fotakopoulou, & Boroditsky, 2010).

Human beings use different types of spatial representations to understand temporal dynamics (for a review, see Núñez & Cooperrider, 2013). One of these models describes the passage of time along a left-to-right spatial representation. For instance, accumulating evidence shows that participants who have been exposed to left-to-right writing/reading habits are better at judging short time intervals or durations with the left response side and long durations with the right response side than vice versa (i.e., the *Spatial-Temporal Association of Response Codes* (STEARC) effect), as reported in both visual (Vallesi, Binns, & Shallice, 2008) and auditory (Ishihara, Keller, Rossetti, & Prinz, 2008) modalities. An advantage of putative left-to-right temporal representations also emerges even when a lateralized response code is not required by the task (e.g., Di Bono et al., 2012). At the cortical level, through electrophysiological recordings, it is possible to reliably track the advanced preparation of the relevant response side in compatible conditions only. In a bimanual version of the STEARC task, a negative-going brain wave was detectable at the level of the scalp over the motor regions of the right hemisphere (suggesting left hand response preparation) before short intervals, and over the motor scalp regions of the left hemisphere (suggesting right hand response preparation) before longer ones (Vallesi, McIntosh, & Stuss, 2011). This suggests that time could be represented along a left-to-right oriented timeline, at least in the experimental settings in which responses have to be given with the fingers of both hands arranged in a horizontal position. This spatiotemporal compatibility phenomenon (i.e., the STEARC effect) disappears in individuals who have been exposed to a mixture of writing/reading habits, as recently shown in a sample of Israeli people (Vallesi, Weisblatt, Semenza, & Shaki, 2014).

The role of spatial attention in the generation of the STEARC effect has often been implicitly or explicitly implied, also in analogy to the spatial representation of numbers (i.e., the *Spatial Numerical Association of Response Codes* (SNARC) effect; e.g., Dehaene, Bossini, & Giraux, 1993; Zorzi, Priftis, & Umiltà, 2002), but not yet directly investigated. One hypothesis could be that, in temporal estimation tasks that imply the representation of a left-to-right oriented timeline, spatial attention is oriented leftward for short durations and then moves rightward for longer durations, thus pre-activating the corresponding response side and favouring performance in compatible mappings (i.e., short duration-left response; long duration-right response). This hypothesis is borrowed from the attention-shift account of spatial compatibility phenomena such as the Simon task (Simon & Rudell, 1967), according to which orienting the attentional focus leftward or rightward in space produces spatial codes that might facilitate left- or right-sided responses, respectively (Notebaert, Soetens, & Melis, 2001; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Stoffer, 1991; Vallesi & Umiltà, 2009).

It was already reported that temporal processing in right hemisphere patients, especially those suffering from spatial neglect (SN), is usually disrupted in several ways (Becchio & Bertone, 2006; Calabria et al., 2011; Danckert et al. 2007; Frassinetti Magnani, & Oliveri, 2009; Husain, Shapiro, Martin, & Kennard, 1997; Magnani, Oliveri, Mancuso, Galante, & Frassinetti, 2011). Moreover, in a recent study, Saj, Fuhrman, Vuilleumier, and Boroditsky (2014) already documented that patients with left SN showed deficits in remembering past-related events as such, suggesting that the representation of time in memory may share cognitive and neural mechanisms with the representation of space. In order to understand the generalizability of these elegant findings, it would be important to investigate whether, not only the mnestic representation of the past, but also the dynamic representation of the present time, in particular that of relatively short events, is disrupted in association with spatial attention deficits, in a way that may affect lateralized motor performance.

With the present study we aimed to test the role of spatial attention in a temporal judgment task (i.e., the STEARC paradigm) by assessing right hemisphere-damaged patients who may have different degrees of SN, that is, inability to direct spatial attention towards the contralesional (left) side of space. Patients with SN, indeed, may suffer from severe deficits in directing spatial attention towards objects, events or representations in the contralesional (usually left) side of space, not primarily due to sensory-motor defects (Bartolomeo, 2007; Heilman & Valenstein, 1985; Vallar, Bottini, & Paulesu, 2003).

If we hypothesize the existence of a mental timeline, the main prediction, when testing SN patients with the STEARC task, is that the left-to-right representation of time, typical of individuals who read/write from left to right, should be disrupted on the left side proportionally with the extent of visuo-spatial attention deficits shown by SN patients. If so, we would observe a reduction in the normally observed spatiotemporal compatibility effect according to which, in left-to-right writers/readers, short intervals are judged faster with a left response than with a right one. A shift from an effect manifesting itself on speed to an effect showing up on accuracy data is possible in patients, as previously reported in the literature (e.g., MacLeod & Nelson, 1984). A pattern of findings in which the emergence of STEARC-like effects is inversely proportional to the degree of spatial attention deficits would bring additional evidence in favour of a key role of spatial attention in the generation of these spatiotemporal compatibility phenomena.

Methods

Participants

For the patients' group, inclusion criteria comprised the presence of a brain lesion limited to the right hemisphere, absence of dementia, substance abuse, psychiatric and degenerative neurological disorders, and visual field defects. The inclusion criteria were documented adequately by clinical history, clinical assessment, and neurological examination. Thirteen consecutive patients with chronic ischemic (N=10) or hemorrhagic (N=3) stroke lesions in the right hemisphere were recruited for this study (mean age: 56.8±10.7 Standard Deviation; 12 males; mean education level in years: 11.5±3.3) from the Gervasutta Hospital in Udine, Italy and the IRCCS San Camillo Hospital Foundation, Venice-Lido, Italy. All patients were right handed as assessed with the Edimburgh Handedness Inventory (Oldfield, 1971; mean: 96±7.4), had normal or corrected to normal vision, and a score above the cut-off on the Mini Mental State Examination (MMSE, mean: 28.3±0.85, range: 27-30, cut-off=24, see Cossa, Della Sala, Musicco, Spinnler, & Ubezio, 1997). All patients were in a chronic stage following brain damage (mean days after lesion: 210, range: 136-640). Lesion locations were documented for each patient with CT or MRI scans. An overall representation of the lesion overlap is reported in Figure 1.

Four extra patients (all with a clinical diagnosis of SN) were excluded from the present study because they did not pass the pre-established criterion of 14 correct trials out of 20 in the practice phase of the STEARC task, which confirms previous findings showing that right hemispheric lesions, especially in the presence of SN, impair time perception (Calabria et al., 2011). Finally, two extra patients were excluded because, although they passed the criterion in the first practice phase, their accuracy level was extremely low during the test phase (below 55%).

A group of 15 neurologically healthy control participants was also recruited (mean age: 63±10; 13 males; mean education level in years: 12±3.3). All control participants were right handed (mean Edimburgh Handedness Inventory score: 96±5.8), had normal or corrected to normal vision and reported no history of neurological/psychiatric problems. The control group did not differ with respect to the patient sample in terms of age [$t(26)=1.54$, $p=.13$] or education [$t(26)=0.45$, $p=.65$].

One extra control participant was excluded because his accuracy level on the STEARC task was below 55%. All participants gave their informed consent before being enrolled into the study. The procedure used was approved by local ethics committees based on the hospitals where data collection took place.

----Insert Figure 1 about here----

Neuropsychological assessment

All patients were administered five sub-tests from the Behavioral Inattention Test – BIT (Halligan, Cockburn, & Wilson, 1991; Wilson, Cockburn, & Halligan, 1987): Line Crossing, Letter Cancellation, Star Cancellation, Line Bisection, and “Figure and Shape” Copying. Cut-off scores from the BIT manual were used (see Table 1). Due to the small group of SN patients, the scores of the Copying sub-test were not used for correlation analyses with the STEARC task (see below), since they were distributed in a ordinal scale with 4 points only and offered no sufficient inter-subject variability. All patients were also administered the MMSE (Folstein, Folstein, & McHugh, 1975; Italian version by Magni, Binetti, Bianchetti, Rozzini, & Trabucchi, 1996) to exclude the presence of severe cognitive deficits. Table 1 includes the demographic information of the patients and their scores on the five BIT sub-tests (see below). All patients had pathological scores in at least one BIT subtest. Moreover, all but one (#6) met the criteria for neglect diagnosis according to the cut-off of the BIT total score (<130).

Apparatus and stimuli

For the experimental part of the study, the task was similar to that in Vallesi and colleagues (2008). All participants viewed the screen of a personal computer at a distance of approximately 60 cm. A central cross (2 yellow crossed bars, 1.0 x 0.5 cm) was used as fixation. The imperative stimulus consisted of a downward pointing white arrow (a 1.5 x 1 cm bar attached to a 0.5 cm arrowhead with a maximum width of 2 cm).

----Insert Table 1 about here----

Procedure and Task

A trial started with the central fixation cross, lasting for a foreperiod (FP) of 1 or 3 sec. The 2 values of the FP were presented randomly on an equal number of trials. After the FP elapsed, the arrow requiring a response was presented. The task consisted of pressing a key (‘B’) with the index finger of the dominant (right) hand and another key (‘N’) with the middle finger of the same hand according to the duration of the fixation cross. This unimanual stimulus-response mapping, which is known not to change the STEARC phenomena (see Vallesi et al., 2008, Experiment 4), allowed us to include also hemiparetic patients with motor problems affecting the left (i.e., controlesional) hand, that is, the hand on the controlesional side. In order to avoid linguistic biases, the ‘B’ and ‘N’ keys were labelled and referred to in the instructions with red and green colors, respectively. The stimulus duration (short, long) / response key (‘B’,’N’) assignment was inverted after 80 trials. The order of presentation of the 2 possible S-R mappings was counterbalanced across participants. After the response execution, a 1 sec blank separated one trial from the other. In the test phase, there were 40 trials for each of the four main conditions of the task, given by the 2 by 2 combination of foreperiod duration and response side. A familiarization block, consisting of 20 trials, preceded each experimental block with opposite S-R mappings. During this phase, a visual feedback was displayed for 1 second soon after the response. The feedback provided during the initial practice phases consisted of a green string (in Italian): “Good! Go on with the next trial!”, for correct responses, and a red string: “Wrong response, be careful!” plus a sound (a 1500 Hz pure tone lasting 50 ms) for incorrect responses. Another red string: “Too slow, try to be faster!” (plus the 1500 Hz sound) was presented for slow responses (>1500 ms) or null responses. The familiarization phase was repeated until participants achieved 14/20 correct responses or more for a maximum of 3 times. All participants included in this study reached this criterion after 1-3 familiarization phases (see the Participants section for details).

Data Analysis

Trials with response times (RTs) outside the 100-2000 ms range and with anticipated responses (i.e., responses before the target) were discarded from further analyses. In addition, the first trial of each block was eliminated. A Stimulus duration (1 vs. 3 sec) x Response side (left vs. right) x Group (patients vs. controls) mixed ANOVA (2x2x2) was employed for the mean RTs on correct trials. The non-parametric Mann-Whitney U test was used to assess differences between the two groups in the different accuracy conditions, since accuracy data were not normally distributed in the control group (which showed ceiling effects). Accuracy data were normally distributed in the right-hemispheric patients but showed ceiling effects in the healthy controls. Accuracy data did not suffer from ceiling effects in the patients' group. This is an ideal situation in which accuracy measures may become more informative than RTs (e.g., Macleod & Nelson, 1984), which allowed us to compute correlations between these measures and the scores obtained by patients in the BIT sub-tests. Given that we had a priori hypotheses on these correlations, that is, an expected positive relationship between STEARC measures and spatial attention abilities as measured with the BIT sub-tests, we did not correct our results for multiple comparisons. Convergence of evidence from significant correlations with more than one BIT sub-test could moreover be seen as a further safeguard against type I errors.

It is worth noting that a closer look to the performance data on the Line Crossing, Letter Cancellation and Star Cancellation BIT sub-tests allowed us to observe that our patients' group committed 95% of the total omission errors on the left side and 5% on the right, confirming that mostly left SN signs were present in our patients' group.

Results

Response Times

Mean RTs are displayed in Figure 2A. The patients' group was slower than the healthy controls [average RT ± standard deviation: 907±238 vs. 488±83; *F*(1,26)=40.78, *p*<.0001, partial eta squared: .61]. Moreover, responses were faster for long than for short target durations [603±260 vs. 762±289; *F*(1,26)=96.93, *p*<.0001, partial eta squared: .79]. No other effect was significant (for all, *ps*>.26). However, given our a priori hypotheses on the presence of a STEARC effect in the controls' group and not in the patients' group, we explored the presence of this effect by performing a 2 Response side by 2 FP duration repeated measures 2x2 ANOVA in each group separately. The results showed the presence of a significant 2-way interaction between response side and FP duration (i.e., the STEARC effect), in the control group [*F*(1,14)=8.81, *p*=.01, partial eta squared: .39], thus confirming the previous literature, but not in the patients' group (*p*=.8).

----Insert Figure 2 about here----

Accuracy

The percentage of accurate responses is displayed in Figure 2B. The accuracy level was lower in the patients' group than in the healthy controls for all the four experimental conditions (for all, *U*(26) < 15.5, *Z* < -3.75, *p*<.00014; average accuracy ± standard deviation: 73.8±12.3% vs. 97.9±1.87%). Visual inspection of Figure 2B, showed that, while the control group performed at ceiling in terms of accuracy, the STEARC effect was numerically present in the patients' group (i.e., more correct responses for short-left and long-right duration-response side combinations than vice versa). To assess this pattern statistically, we performed an exploratory 2x2 repeated measures ANOVA on this group with Stimulus duration and Response side as the independent factors and Percentage of correct responses as the dependent variable. However, the 2-way interaction between stimulus duration and response side was not significant (*p*=.39).

Correlation between SN and STEARC measures

The results of all correlation analyses between the patients' scores in the BIT sub-tests and accuracy STEARC measures are shown in Table 2. The overall accuracy on the STEARC task positively correlated with the scores obtained by the patients on the Line Crossing (*r*=.69, *p*=.009) and Star Cancellation (*r*=.64, *p*=.019) tests. Moreover, accuracy in the condition in which short durations had to be responded to with the left-most finger (i.e., right index) was also positively correlated with both the Line Crossing (*r*=.82, *p*=.001) and Star Cancellation (*r*=.77, *p*=.002) BIT sub-test scores. In the same condition, there was a non-significant tendency for a positive correlation between accuracy and Line Bisection task (*r*=.53, p=.06). The Line Crossing (*r*=.58, *p*=.036) and Star Cancellation (*r*=.55, *p*=.049) scores were also positively correlated with accuracy on the long duration responded to with the right-most finger (i.e., the right middle finger). In other words, in the spatiotemporally compatible STEARC conditions (i.e., short-left and long-right), there was a positive correlation between accuracy level and spatial attention capacity (i.e., the inverse measure of SN signs, as indicated by the scores on the BIT sub-tests).

Importantly, a measure of the STEARC effect with short durations (i.e., the accuracy difference between left- and right-most responses) was positively correlated with scores obtained in the Star Cancellation (*r*=.57, *p*=.04) and Line Bisection (*r*=.56, *p*=.044) BIT sub-tests, and there was also a non-significant tendency for a positive correlation also in the Line Crossing sub-test (*r*=.54, *p*=.059), as shown in Figure 3. No correlation was observed between STEARC effect with long duration (i.e., the accuracy difference between right- and left-most responses) and any of the BIT sub-tests (for all, *ps*>.63). The Letter Cancellation sub-test did not show any correlation with accuracy measures (for all, *ps*>.28).

We also explored for correlations between RT STEARC measures and scores on the BIT sub-tests for both short and long durations. No correlation was significant (for all, *ps*>.5), confirming that accuracy measures are more sensitive to the experimental effects than speed measures in the case of our patient sample.

----Insert Figure 3 about here----

----Insert Table 2 about here----

Discussion

A left-to-right representation of elapsing time has been documented in neurologically healthy individuals adopting writing/reading systems from left-to-right (e.g., Vallesi et al., 2014). This spatial representation of time along the horizontal axis is for instance manifested in behavior in terms of shorter RTs when judging shorter durations with the left response side and longer durations with the right response side than vice versa, a behavioral phenomenon known as the STEARC effect (e.g., Ishihara et al., 2008; Vallesi et al., 2008; 2011; 2014). With the present study, we aimed to better understand whether spatial attention is an important cognitive determinant of this spatial representation of time in a dynamical spatial-temporal task, where not only the mnestic representation of the past (see Saj et al., 2014), but also the dynamic representation of the present time, in particular that of relatively short events, could be disrupted in association with spatial attention deficits, in a way that may affect lateralized motor performance. We tested this hypothesis on a group of right hemisphere-damaged patients with different degrees of spatial attention deficits (i.e., SN signs) as measured by means of sub-tests of the BIT battery (Wilson et al., 1987).

While patients did not show a STEARC effect in terms of speed, and this effect was only numerically (but not reliably) present in their accuracy level, a normal STEARC effect was documented in the RTs of the control group, replicating previous findings. With regard to the patients' data, we showed that a higher degree of spatial attention deficits was associated with problems in temporal judgment, as revealed by a positive correlation between general accuracy on the STEARC task and two BIT sub-tests (i.e., Line Crossing and Star Cancellation). This finding corroborates the existing literature showing a strong link between spatial and temporal processing in the right (especially parietal) cortex (e.g., Calabria et al., 2011; Magnani et al., 2011; Walsh, 2003). This finding could be however interpreted as a manifestation of a more general deficit in magnitude estimation in right brain-damaged patients (e.g., Walsh, 2003), a working hypothesis which should be tested in future studies by targeting this more general function as well as time estimation within the same experimental session.

More specifically, accuracy at judging short durations with the left effector and long durations with the right effector, that is, the conditions that show compatibility with a left-to-right representation of time, were both positively correlated with the same BIT sub-tests. Finally, and most critically, the accuracy STEARC effect calculated on the short durations was also positively correlated with three BIT sub-tests (although as a non-significant tendency in the case of the Line Crossing test). These results, overall, show that spatial attention should work well for STEARC-like phenomena to emerge, thus corroborating the hypothesis that spatial attention mechanisms are a key factor, together with cultural influences (e.g., Vallesi et al., 2014), in the representation of elapsing time.

These results extend those of a recent study (Saj et al., 2014) in which lateralized amnesic signs were reported, selectively for past-related episodes, in left SN patients. Our findings, however, suggest that, not only episodic memory representations of temporal events, but also the dynamic online representation of elapsing time can be represented in a spatially defined manner (in our paradigm, with a left-to-right orientation), a representation that could be disrupted when spatial attention is not properly oriented.

Although an overall accuracy STEARC effect was numerically present in the patients' group (see Figure 2B), this did not emerge statistically either for short or for long duration, contrary to the logical prediction that the STEARC effect for long durations should not be affected by left-ward attentional deficits. The latter prediction was however indirectly confirmed by a lack of correlation between any BIT sub-test scores and STEARC effect for long durations (see Table 2). A possibility for a lack of significant STEARC effect in our group of patients, apart from the small sample size, is the noise due to more basic problems in estimating temporal durations which seems intrinsic in patients with damage in right fronto-parietal regions (e.g., Calabria et al., 2011; Danckert et al. 2007). Indeed, patients' performance was overall much worse than that of controls in this temporal judgment task (e.g., they committed about 24% more errors than controls).

A limitation of the present study was that most of the reported significant correlations between BIT sub-test scores and STEARC indexes would not survive a stringent (e.g., Bonferroni) multiple comparison correction. Although we had a priori directional hypotheses and we obtained convergent results from more correlation analyses, the lack of multiple comparison correction implies that our correlational results should be interpreted with caution. Future studies employing bigger sample sizes and higher statistical power should ideally replicate and strengthen the results obtained here.

Conclusions

The mental representation of an elusive concept such as time is difficult to capture, given that we have no dedicated sense for this dimension of our internal and external world. Previous studies showed that spatial representations, such as a mental time line developing horizontally from left-to-right, are able to account for behavioral effects on simple temporal judgment tasks. The present neuropsychological study corroborates and extends previous literature on the critical role of spatial attention mechanisms in generating a mental time line, which is indeed disrupted proportionally with the presence of disorders in spatial attention. Future work, involving the recruitment of a higher number of left and right hemisphere-damaged patients, should unveil which brain areas are critically involved in the cross-talk between space and time representations. As a more general conclusion, the present study represents a specific contribution to the hot debate on how mental and neural representations of abstract concepts, which cannot be directly experienced through our senses, may partially rely on our richer spatial representations.

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Tables

Table 1. Demographic characteristics and scores in the BIT sub-tests (with cut-off values) of patients with right hemispheric lesions.

Patient number	EHI	Sex	Education (years)	Age (years)	Days from lesion	Lesion Type	MMSE	Line Crossing (34)	Letter Cancel. (32)	Star Cancel. (51)	Line Bisect. (7)	Figure & Shape Copy (3)
1	100	M	13	63	168	IS	28	34*	36	40*	2*	2*
2	100	M	13	38	203	HS	28	33*	30*	37*	3*	2*
3	83	M	13	68	136	IS	29	36	34	47*	7*	3*
4	100	M	13	60	215	HS	28	36	27*	47*	5*	2*
5	83	M	8	71	221	IS	29	35	32*	44*	8	2*
6	100	M	8	39	176	IS	30	36	38	51*	9	4
7	100	M	8	64	141	IS	29	34*	29*	45*	4*	1*
8	100	M	8	53	190	IS	28	31*	23*	35*	0*	1*
9	100	M	17	52	145	IS	28	36	26*	48*	2*	2*
10	83	M	13	59	136	IS	28	35	30*	42*	2*	2*
11	100	F	10	45	183	HS	27	31*	38	36*	5*	1*
12	100	M	8	61	640	IS	27	36	38	47*	7*	1*
13	100	M	17	65	176	IS	29	36	32*	48*	9	1*

EHI = Edinburgh Handedness Inventory score; MMSE = Mini Mental State Examination score; IS = ischemic stroke lesion etiology; HS = hemorrhagic stroke lesion aetiology. * = pathologic score according to the cut-offs reported in Wilson et al. (1987).

Table 2. Results of the Pearson's correlation analyses between the patients' scores in four BIT sub-tests and various accuracy STEARC measures.

	BIT sub-test			
	Line Crossing	Letter Cancellation	Star Cancellation	Line Bisection
Total Accuracy	r=.69, p=.009*	r=-.27, p=373	r=.64, p=.019*	r=.37, p=.211
Short Left	r=.82, p=.001*	r=-.11, p=.718	r=.77, p=.002*	r=.53, p=.063§
Short Right	r=.40, p=172	r=-.30, p=.323	r=.40, p=.177	r=.30, p=.323
Long Left	r=.48, p=.1	r=-.32, p=.288	r=.37, p=.207	r=.08, p=.805
Long Right	r=.58, p=.036*	r=-.23, p=.451	r=.55, p=.049*	r=.28, p=.361
STEARC Short	r=.54, p=.059§	r=.16, p=.594	r=.58, p=.04*	r=.56, p=.044*
STEARC Long	r=.15, p=.63	r=.09, p=.777	r=.12, p=.687	r=-.04, p=.892

** = Significant result ($p<.05$); § = Non-significant tendency ($p>.05$ and $<.07$).*

Figure Captions

Figure 1. Overlap of right hemisphere lesions of the 13 patients reconstructed and superimposed in a single individual MNI normalized brain. The brain images were obtained within the same week as the testing session.

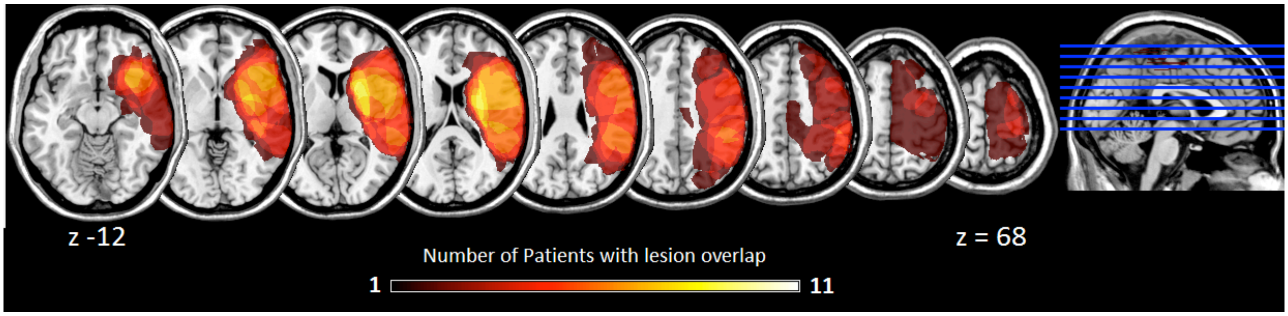

Figure 2. Mean response times (Panel A) and mean Accuracy (Panel B) as a function of stimulus duration and response side ("left" and "right" indicate the right index and middle fingers, respectively) in both patients and healthy controls. Error bars indicate Standard Errors of the Mean.

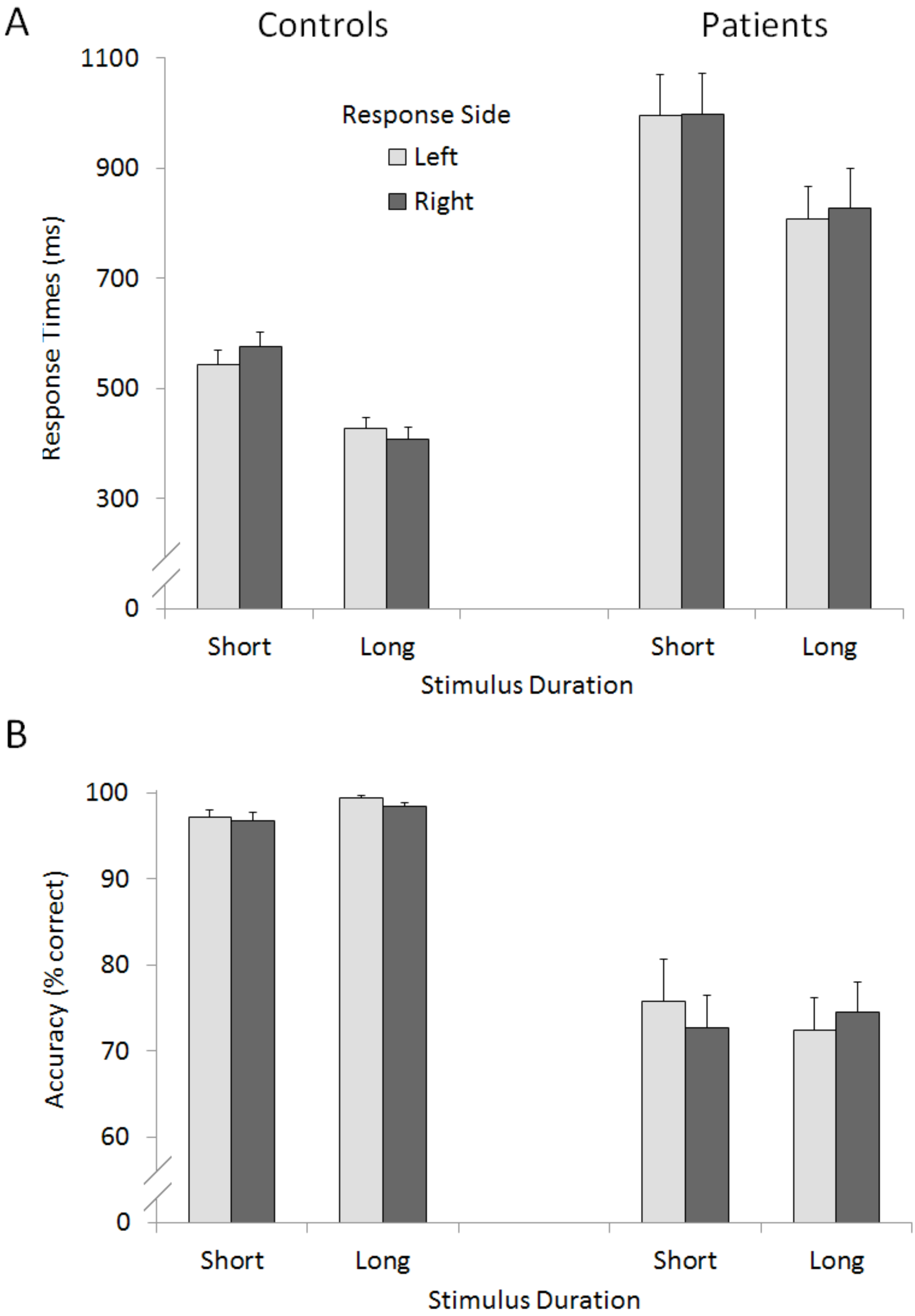
A
Controls
Patients
Response Side
□ Left
■ Right
Response Times (ms)
1100
900
700
500
300
0
Short
Long
Short
Long
Stimulus Duration
B
Accuracy (% correct)
100
90
80
70
60
0
Short
Long
Short
Long
Stimulus Duration

Figure 3. Correlations between accuracy STEARC effect for short durations (left minus right finger percentage of correct responses) and scores on three BIT sub-tests (from left to right): Star Cancellation, Line Bisection, and Line Crossing. Overlapping scores were slightly shifted in the graphs for illustration purposes only.