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Short communication

Visual trajectory perception in humans: Is it lateralized? Clues from online rTMS of the middle-temporal complex (MT/V5)

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ABSTRACT

Inconsistent observations have been reported in the literature regarding the asymmetrical contribution of higher visual areas of the left and right hemispheres to visual motion processing. In the present experiment, we tested for hemispheric asymmetry of the middle-temporal complex (V5/MT), which is a key-component of the visual motion network, by using rTMS applied over left or right V5/MT during a visual trajectory perception task. The results showed that the effect of rTMS was to enhance individual hemispheric asymmetries present when the test was performed without rTMS. The more general meaning of these results is that there are robust individual hemispheric asymmetries in motion perception but no general pattern of hemispheric differences.

Visual motion has two distinct properties (direction and speed), and is especially concerned with the duality between the spatial and temporal aspects of perceptual processing [12]. As a result, inconsistent observations have been reported regarding the asymmetrical contribution of higher visual areas of the left and right hemispheres to visual motion processing. Although behavioural results suggest a strong right hemisphere dominance for visual trajectory perception [4], brain imaging experiments consistently showed that visual motion stimuli induce bilateral hemispheric activation in extrastriate visual cortex [5,20,24]. However, it should be considered that the averaging technique used in neuroimaging studies may mask hemispheric asymmetries in individual subjects. In contrast, individual ERP analyses revealed that motion visual evoked potentials originate in one hemisphere in most adult subjects regardless of left or right hemifield of stimulation [11,13].[1] Yet, behavioural evidence of visual hemifield asymmetric performance is lacking in these reports. Finally, studies using direct stimulation of motion-related extrastriate visual areas suggest a special role for the left hemisphere that was found to produce moving phosphenes more reliably than the right hemisphere [2,17].

While numerous motion-related brain areas have been identified [5,9], the middle-temporal complex (V5, the human homologue of monkey area MT, MST and adjacent motion selective cortex—usually labelled V5/MT-) is known to be the key-component of the visual motion perception network [7,21,23,24]. Areas near the primary visual cortex are organized retinotopically and strictly contralaterally relative to the visual hemifields. Conversely, V5/MT receives information from both visual hemifields [20,21]. Consistent with the fact that V5/MT receives very dense interhemispheric connections [8], it was shown that ipsilateral field representation in this area is due to the transfer of visual motion information from its contralateral homologue [10]. This observation leads to two considerations. First, at a behavioural level, it is necessary to use classical methods of comparing reaction time (RT) differences between crossed and uncrossed visuomotor combinations to test interhemispheric transmission [15] and hemispheric differences of visual motion perception. To our knowledge, very few behavioural studies have adapted this RT paradigm to a complex visual trajectory perception task [4]. Second, at the neuroimaging level, it remains unclear whether there are hemispheric asymmetries at the level of V5/MT and further studies should be pursued.

A direct way of testing hemispheric asymmetries in V5/MT consists of using TMS over left or right V5/MT to modify brain activity while controlling all combinations of responding hand and visual hemifield of stimulus presentation. To do that, in the present study, we used the visual trajectory perception task developed

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[1] In these studies, most subjects exhibited a right hemispheric dominance (about 65%), i.e., a non-negligible proportion of the subjects revealed a left dominance.

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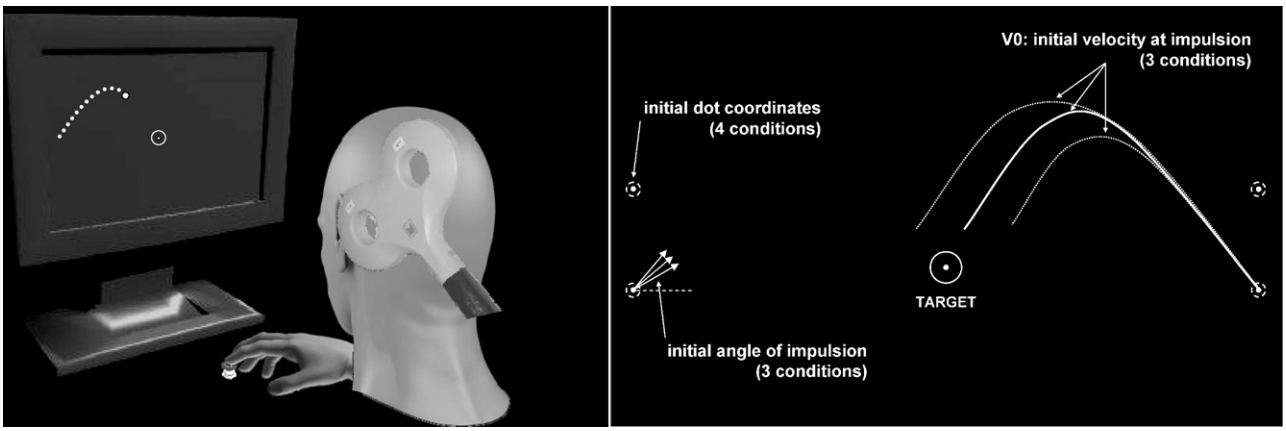

Fig. 1. Illustration of the experimental display.

by Boulinguez et al. [4] during 10 Hz rTMS over the left or right hemisphere.

Six neurologically normal men with normal or corrected-to-normal vision participated in the experiment (ages 19–24 years). They were naive as to the purposes of the study. All selected participants were strongly right handed [6]. The experiment was undertaken with the understanding and written consent of each subject and was carried out according to the principles laid down in the Helsinki Declaration.

The basic experimental procedure was similar to that of Boulinguez et al. [4]. It was partly modified with respect to that study in order to present visual stimuli on a computer screen (21 in.) and to reduce the total number of trials per block. Fig. 1 depicts the experimental display. Subjects were seating in darkness in front of a computer screen, the head fixed by means of a bite-bar so that their eyes were precisely positioned at the centre of the screen. Visual stimuli were lateralized dot (Ø 0.3 cm) ballistic trajectories simulating the effects of gravity (see [4] for equations). Trajectories varied with respect to the visual hemifield of presentation, to the initial position of the moving dot (only the two upper positions of [4] were used in the present experiment), to the initial direction of the moving dot (three directions per initial position), and, finally, to the initial velocity at impulsion (three conditions per initial direction). All trajectories were centripetal, starting at outer positions of the screen and ending near the central fixation point. As a result of varying initial velocity at impulsion, each stimulus (i.e., each visual field by initial position by initial direction condition) could have three different endpoints: one inside the 2 cm diameter central target, one 2 cm ahead and one 2 cm beyond the target. The distance between the starting points of the visual stimuli and the central fixation point subtended $\pm 25^{\circ}$ of visual angle. Trajectories lasted between 1200 and 1400 ms. RTs were recorded using a button placed on subjects' sagittal axis and pressed with the index finger. The procedures used to control the hardware (Pentium PC), generate stimuli and record subjects RT were programmed in Delphi 4.0. RTs were recorded with a sampling rate of 1000 Hz.

Subjects were asked to keep their gaze steadily on the fixation point (center of the target) throughout the procedure. A trial started with the presentation of both an auditory alerting cue and the stationary dot indicating the initial location of the stimulus. After 2 s, the dot started to move along a ballistic trajectory induced by an initial impulse. Subjects were instructed to predict by pressing the button if the dot trajectory presented in one or the other hemifield would end into the central target. On half of the trials the dot ended into the target while the other half trials were equally distributed between "too short" and "too long". Trials in which subjects pressed the button while stimulus trajectory was not going to end within the central target were considered errors. At the beginning of the session subjects were encouraged to respond as fast as possible with a minimum error rate. Since hand and visual hemifield effects may interact in this kind of task (because of interhemispheric transmission, e.g., [4]), it is likely that these two factors are confounded when using only one hand for response. Therefore, there were two blocks of trials, one for the left hand and one for the right hand. The order was counterbalanced across subjects and conditions. Each block was composed of 48 trials (2 trials per starting point by initial direction by visual hemifield condition). Left hand and right hand data were collapsed for the analysis of visual field asymmetries. In order to obtain a stable level of performance, subjects were given 6 practice blocks prior to testing.

Given the duration of the visual trajectories, repetitive rather than single-pulse TMS was applied. rTMS was delivered by means of a 2T-Magstim 200 magnetic stimulator (Novametric) via a 70 mm figure-of-eight coil. Stimulus intensity was adjusted individually by reference to motor-cortex excitability. To this aim, we used the classical procedure consisting of recording motor-evoked potentials (MEP) of the *right abductor digiti minimi* muscle (by means of a Viking IV electromyography unit, Nicolet biomedical, USA) following stimulation of its motor-cortical representational field. Individual motor thresholds, defined as the lowest TMS intensity capable of evoking 5 out of 10 MEP with an amplitude of at least 50 mV, were used to normalize stimulation intensity across subjects. 10 Hz rTMS was delivered during 1 s; intensity was set at 80% of MT; intertrial intervals were longer than 10 s. This condition complies with the international recommendations for safety of rTMS [14]. The initiation of the train of potentials was synchronized with the start of the moving stimulus. Given the distribution of RT data, the 1 s rTMS duration ensured that 99.48% of all behavioural responses were performed during stimulation.

The site of TMS was chosen on the basis of previous studies [3,19]. Since the phosphene threshold is usually higher than the motor threshold in individual subjects [18], it must be noticed that, for each subject, the normalized stimulation intensity used in the present study (80% of MT) was always below individual phosphene thresholds. A calibrated latex cap was used to facilitate the placement of the coil in the same anatomical position for all subjects. The location chosen was 5–6 cm lateral to the mid-sagittal plane and 3–4 cm above the mastoid-inion line. To control for non-specific effects of rTMS, we used an inactive coil positioned at the location noted above. Since the active coil was sufficiently distant from the skull, it was unlikely that it induced depolarization of cortical neurons. The behavioural effects of real rTMS were compared to

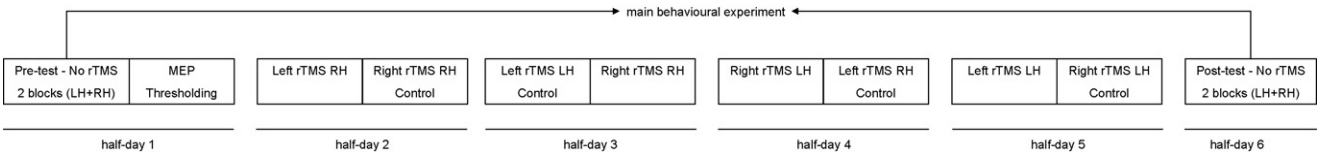

Fig. 2. Timeline of the experiment. rTMS was applied during half-days 2–5. Each session was composed of one real rTMS and one control rTMS block presented in a pseudo-random order across subjects.

the above rTMS control condition. This sham procedure controlled for RT effects of acoustic noise and vibrations generated by coil discharge.

The design included three types of blocks: purely behavioural (no rTMS), behavioural plus rTMS, and control rTMS blocks. The whole experiment was performed over 6 half-days for one subject. The sequence of events is shown in Fig. 2. During half-day #1, the first behavioural blocks were performed (pre-test session: one left hand block plus one right hand block). Then, the location for stimulation was found and individual thresholds were determined. On half-days 2–5, each session consisted of one real rTMS and one control rTMS block, so that all conditions of rTMS side (left and right) and Hand (left and right) were tested. Blocks were presented in a pseudo-random order across subjects by balancing the alternation between left and right rTMS for both real and control trials. All in all, each subject performed 12 blocks for a total of 576 trials.

Dependent Variables were defined as follows: *Errors*: the percentage of incorrect responses (false alarms: responses to trajectories ending outside the central target) was calculated with respect to the total number of stimuli presented in each condition. It was assessed statistically by group analyses only. *RT*: Only in 50% of the trials the dot trajectories ended into the central target. The fact that individual error rates found across conditions ranged from 0 to 20.8%, (mean 6.9%) and therefore are far from chance level (50%) makes RT data analysis reliable. RT were averaged for each visual stimulus (i.e., for each of the 6 "valid" trajectories presented within each visual field). These conditions were paired for individual statistical analyses. False alarms were excluded from RT analyses. *ΔRT*: We used the variable ΔRT to estimate the behavioural effect of online rTMS. It was calculated by subtracting the corresponding control rTMS condition from RT obtained in the actual rTMS condition. A negative value indicates that online rTMS has a facilitating effect whereas a positive value indicates that rTMS disrupts trajectory perception. The magnitude of ΔRT also measures the strength of the effect.

Analyses, Control tests: Pre- and post-tests were intended to reveal visual field asymmetries and possible long term behavioural effects of rTMS on visual field asymmetries. A first analysis revealed no difference between pre- and post-tests (all ps > .15); thus, data were collapsed for further analyses and labelled as "main behavioural experiment". Individual analyses of RT were performed by means of a 3 Experiment (main behavioural, control rTMS left, control rTMS right) × 2 Visual Field (left, right) ANOVA. Post hoc analyses (Newman-Keuls) were used when necessary. The same ANOVA was also applied to errors data at a group level.

Analyses, rTMS effects: A 2 TMS (left, right) × 2 Visual Field (left, right) ANOVA was applied to individual ΔRT data. Post hoc analyses (Newman-Keuls) were used when necessary. Finally, in order to assess the statistical validity of interpreting ΔRT as a facilitating or an inhibitory effect, we performed direct comparisons between RTs obtained in the rTMS condition and in the corresponding control rTMS condition when necessary (*t*-tests). The same ANOVA was also applied to errors data at a group level.

Results, Control tests: The analysis of the percentage of false alarms did not reveal either significant effect of the type of experiment (main behavioural, control rTMS left, control rTMS right) or of visual field at the group level (mean 6.9%, all ps > .57). Individual RT analyses are presented in Table 1. Not surprisingly, in 5 of 6 subjects, at least one or both control TMS experiments provided longer RTs than the main behavioural experiment. However, importantly, the individual patterns of visual field asymmetries observed in the main behavioural experiment were not changed in the control TMS conditions. Four of 6 subjects revealed a significant visual field asymmetry: three provided shorter RT in the left visual field (BE, MA, TT) while one provided shorter RT in the right visual field (BF).

Results, rTMS effects: No effect was observed on percentage of errors at the group level (mean 7.4%, all ps > .46). Individual analyses of ΔRT are presented in Table 2 and Fig. 3. Interestingly, the four subjects who revealed significant visual field asymmetries in the main behavioural experiment provided significant effects of rTMS side on ΔRT. More precisely, the 3 subjects who showed asymmetries favouring the left visual field in the main behavioural experiment (BE, MA, TT) showed a significant improvement of trajectory perception under rTMS of right V5/MT. Conversely, subject BF who provided asymmetries favouring the right visual field in the main behavioural experiment showed a significant improvement of trajectory perception under rTMS of left V5/MT. In order to statistically assess the relation between visual field asymmetries in the main behavioural experiment and the asymmetry of rTMS effects across subjects, we applied a correlation analysis between two indexes of asymmetry calculated for each condition and each subject. Each index was calculated by subtracting right from left values. Results are presented in Fig. 3. The visual field asymmetry observed in the main behavioural experiment remarkably predicts the differential effect produced by stimulating left and right V5/MT ($r^2 = .94$, $p < .01$). The greater the visual field advantage in the main behavioural experiment, the greater the facilitation induced by rTMS of the contralateral V5/MT (Fig. 4). It must be emphasized that, while behavioural asymmetries without rTMS concern visual field differences, unilateral rTMS facilitation applies to the whole visual field.

Modifying brain activity noninvasively and unilaterally may reveal patterns of cerebral dominance that cannot be assessed with purely behavioural or imaging methods. Our results showed that online rTMS applied over motion area V5/MT can facilitate visual motion processing. This may appear surprising because other studies found that TMS applied online over V5/MT during a motion detection task impairs performance (e.g., [22]). However, our finding is consistent with recent evidence by Silvanto and colleagues [16] who demonstrated that online V5/MT TMS can have a facilitatory effect on behaviour in a motion detection task when the initial activation state of the targeted neural population has been previously modified by rTMS.[2] On the basis of Silvanto and colleagues' conclusions, it can be suggested that the effect of rTMS, as applied in our experiment, enhances the initial activation state of V5/MT

[2] This observation is reminiscent of other studies from Antal and colleagues using transcranial direct current stimulation and showing that external modulation of neural excitability in human MT/V5 can improve visual motion perception (see [1] for a recent review).

Table 1
Individual RT analyses of the different sessions: main Behavioural Experiment (pre- and post-tests are collapsed), Control rTMS left V5/MT, Control rTMS right V5/MT. Displayed data result from the 3 Experiment × 2 Visual Field ANOVA applied to RT. Arrows indicate significant post hoc tests ($p < .05$).

	Experiment			Visual field		
Subject	**Main Behav.**	**Co. TMS left**	**Co. TMS right**	**LVF**	**RVF**	**Interaction**
BE		$F(2,10)=29.8$, $p<.001$		$F(1,5)=10.2$, $p<.05$		ns
	668 ms	715 ms	807 ms	707 ms	754 ms	
		⟷ ⟷				
BF		$F(2,10)=26.6$, $p<.001$		$F(1,5)=7.2$, $p<.05$		ns
	574 ms	674 ms	624 ms	637 ms	611 ms	
		⟷ ⟷				
MA		$F(2,10)=4.8$, $p<.05$		$F(1,5)=17.3$, $p<.01$		ns
	760 ms	700 ms	760 ms	727 ms	753 ms	
		⟷				
MW		$F(2,10)=4.2$, $p<.05$		ns		ns
	640 ms	737 ms	688 ms			
		⟷				
SM		$F(2,10)=30$, $p<.001$		ns		ns
	510 ms	591 ms	574 ms			
		⟷				
TT		$F(2,10)=23.1$, $p<.001$		ns		$F(2,10)=4.4$, $p<.05$
	559 ms	669 ms	623 ms			The Visual Field effect is significant only for the Main Behavioural experiment (543 vs. 576 ms for LVF and RVF, respectively, $p<.01$)
		⟷ ⟷				

during the initial part of the stimulation. In other words, the stimulation intensity we used was too low to induce moving phosphenes and impair motion processing, but high enough to enhance the baseline activity of the area and thus induce a better processing of visual motion. Our results show consistent individual effects, both at a pure behavioural level and at the level of rTMS effects (Fig. 3). Without rTMS, 4/6 subjects revealed a consistent visual field asymmetry (favouring the left visual hemifield for three of them). The effects of rTMS were also variable across individuals: 4 of 6 subjects revealed a significant improvement of trajectory perception, 3 of them showed an improvement under right rTMS only and 1 under left rTMS only. An intriguing observation was that the amplitude of the visual field asymmetry observed without rTMS was found to be tightly correlated with the amplitude of the asymmetrical effect of left and right rTMS of V5/MT (Fig. 4). Subjects showing a left visual field advantage enhanced their performance under right rTMS while the subject showing a right visual field advantage enhanced his performance under left rTMS. The two subjects who did not show any significant visual field asymmetry were not significantly affected by rTMS with respect to the respective rTMS control conditions. In short, the greater the observed visual field asymmetry, the greater was the extent of the asymmetrical effect of rTMS of V5/MT.

Table 2
Individual RT analyses of unilateral rTMS effects. Displayed data result from the 2 rTMS × 2 Visual Field ANOVA applied to ΔRT.

Subject	rTMS		Visual field		Interaction
	Left	Right	Left	Right	
BE	$F(1,5)=14.6$, $p<.05$ −10 ms	−156 ms*	ns		ns
BF	$F(1,5)=24.1$, $p<.01$ −62 ms*	11 ms	ns		ns
MA	$F(1,5)=6.2$, $p=.055$ 16 ms	−36 ms*	ns		ns
MW	ns		ns		ns
SM	ns		ns		ns
TT	$F(1,5)=10.6$, $p<.05$ −15 ms	−50 ms*			

* Indicates that the difference between the rTMS condition of interest and the corresponding control rTMS condition (i.e., ΔRT) is significant (*t*-tests, $p < .05$).

From these results it can be concluded that unilateral rTMS reveals functional asymmetries of human complex V5/MT, and that the direction of the cerebral dominance for visual trajectory perception varies across individuals. The type of asymmetry revealed by rTMS is consistent with our previous behavioural study suggesting that the dominant hemisphere may be systematically involved independently from the visual field in which the trajectory is displayed [4]. Indeed, unilateral rTMS effects are not specific to the contralateral visual hemifield but extend to the whole visual field. This pattern of functional lateralization can be explained by the dense interhemispheric connectivity between the left and right medial temporal complex [8,10]. The present results are consistent with previous electrophysiological evidence that motion processing elicits asymmetrical activation of higher movement-related visual areas regardless of visual hemifield [11,13]. They

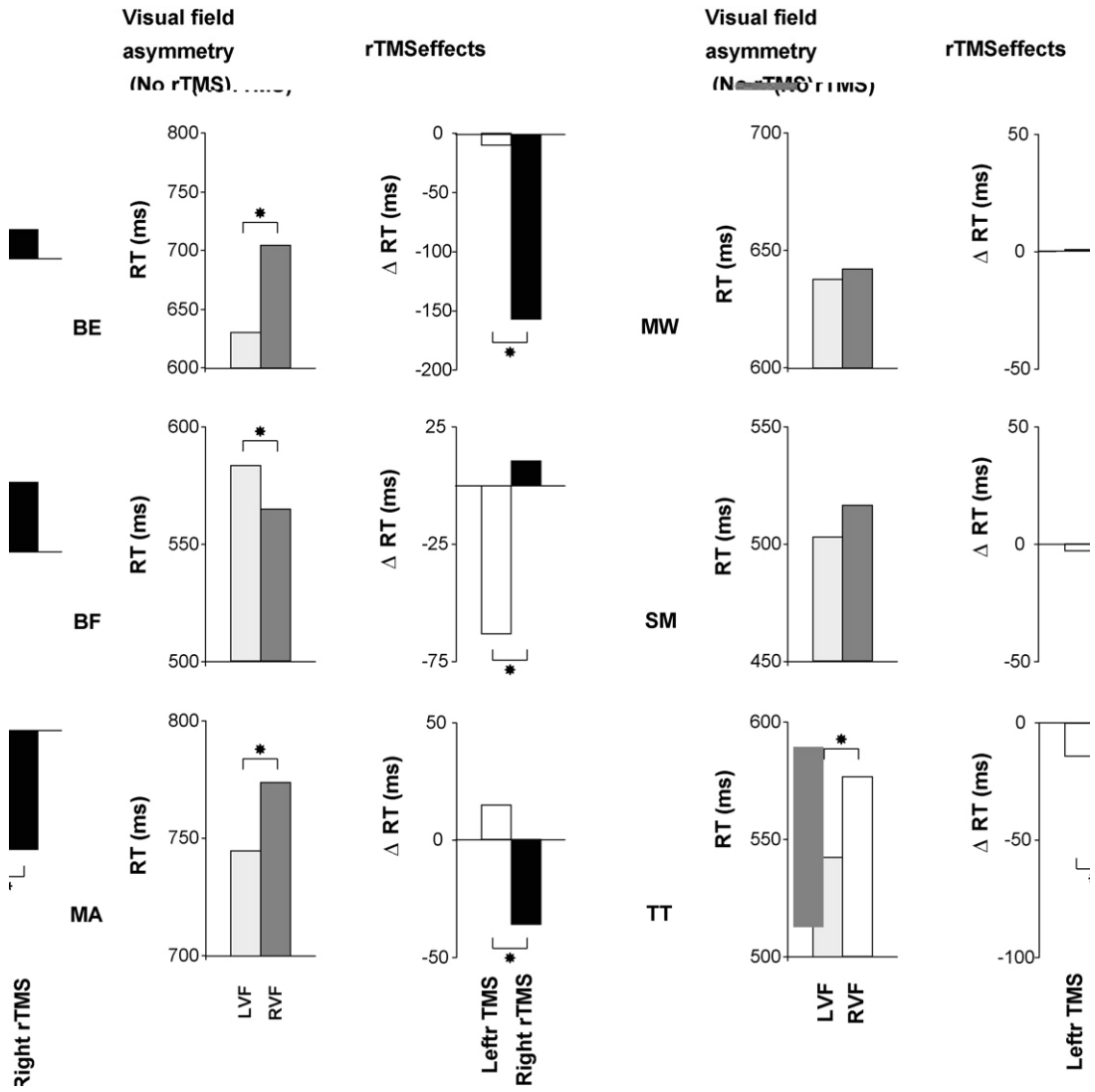

Fig. 3. Individual patterns of asymmetry for Visual Field and rTMS effects. Light grey: Left Visual Field. Dark grey: Right Visual Field. White: rTMS of left V5/MT. Black: rTMS of right V5/MT.

are also in accordance with the evidence provided by the above-mentioned studies that, while a certain variability is observed in individual patterns of lateralization, most subjects exhibit a right hemispheric dominance. Our study provides further evidence in this direction by linking direct unilateral modifications of V5/MT activity to behavioural functional asymmetries for trajectory perception.

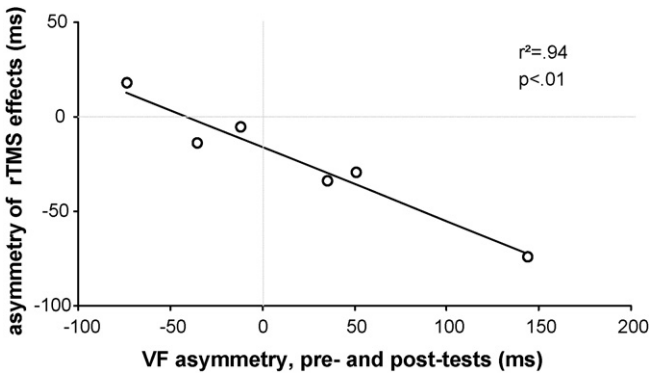

Fig. 4. Asymmetry of unilateral rTMS effects as a function of Visual Field asymmetry observed in the main behavioural experiment.

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