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Reshaping the brain after stroke: The effect of prismatic adaptation in patients with right brain damage☆

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ABSTRACT

Prismatic adaptation has been repeatedly reported to alleviate neglect symptoms; in normal subjects, it was shown to enhance the representation of the left visual space within the left inferior parietal cortex. Our study aimed to determine in humans whether similar compensatory mechanisms underlie the beneficial effect of prismatic adaptation in neglect. Fifteen patients with right hemispheric lesions and 11 age-matched controls underwent a prismatic adaptation session which was preceded and followed by fMRI using a visual detection task. In patients, the prismatic adaptation session improved the accuracy of target detection in the left and central space and enhanced the representation of this visual space within the left hemisphere in parts of the temporal convexity, inferior parietal lobule and prefrontal cortex. Across patients, the increase in neuronal activation within the temporal regions correlated with performance improvements in this visual space. In control subjects, prismatic adaptation enhanced the representation of the left visual space within the left inferior parietal lobule and decreased it within the left temporal cortex. Thus, a brief exposure to prismatic adaptation enhances, both in patients and in control subjects, the competence of the left hemisphere for the left space, but the regions extended beyond the inferior parietal lobule to the temporal convexity in patients. These results suggest that the left hemisphere provides compensatory mechanisms in neglect by assuming the representation of the whole space within the ventral attentional system. The rapidity of the change suggests that the underlying mechanism relies on uncovering pre-existing synaptic connections.

1. Introduction

Prismatic adaptation (PA) was shown to alleviate left neglect in patients with right hemispheric damage (Rossetti et al., 1998). Single and multiple cases studies have demonstrated positive PA effects on various neuropsychological tests or daily life activities (Berberovic and Mattingley, 2003; Maravita et al., 2003; McIntosh et al., 2002; Rode et al., 1998, 2001; Rode et al., 2006a, 2006b; Saevarsson et al., 2009; Tilikete et al., 2001). Although the beneficial effect of PA was confirmed in several group studies (Fortis et al., 2010; Frassinetti et al., 2002; Hatada et al., 2006; Keane et al., 2006; Mizuno et al., 2011; Serino et al., 2007; Shiraishi et al., 2008, 2010; Vangkilde and Habekost, 2010), individual studies have reported interesting discrepancies: short-term but no long-term effects (Nijboer et al., 2008); effects in straight-ahead pointing, partially in-line bisection, but not in visual search (Morris et al., 2004); efficacy in only a subgroup of patients with mild neglect (Mizuno et al., 2011); no effect with only one weekly session (Rode et al., 2015); or the absence of effect (Rousseaux et al., 2006; Turton et al., 2010). These conflicting results across studies may be due to the heterogeneity of neglect syndrome; a better understanding of the mechanisms underlying PA may help identify neglect profiles that respond to PA treatment (Clarke et al., 2015).

Several neuroimaging studies have investigated brain activation while normal subjects were exposed to PA (Chapman et al., 2010;

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Table 1
Demographic and clinical characteristics of the patients.

Patient	Age	Sex	Delay since stroke onset (months)	Etiology	Lesion territory	Visual extinction	Bells test (1st column)
1	43	M	3.1	hemorragic	deep and superficial sylvian	yes	7
2	55	F	48.7	hemorragic	deep and superficial sylvian	yes	2
3	54	M	2.3	ischemic	superficial sylvian	yes	4
4	65	M	46.7	ischemic	deep and superficial sylvian	yes	2
5	50	M	0.9	ischemic	superficial sylvian	yes	4
6	63	F	11.6	ischemic	deep sylvian	no	1
7	59	F	21.3	ischemic	superficial sylvian	yes	7
8	56	M	27.0	hemorragic	deep sylvian	no	1
9	48	F	2.8	hemorragic	deep sylvian	yes	7
10	67	F	22.4	ischemic	deep and superficial sylvian	no	1
11	52	F	0.8	ischemic	superficial sylvian	no	1
12	52	M	14.4	ischemic	superficial sylvian	no	7
13	67	F	6.1	ischemic	deep sylvian	yes	2
14	49	M	4.8	ischemic	deep and superficial sylvian	yes	1
15	44	F	7.7	ischemic	deep and superficial sylvian	no	1

Clower et al., 1996; Danckert et al., 2008; Küper et al., 2014; Luauté et al., 2009). They revealed the involvement of the right cerebellum and the right posterior parietal cortex during the stages of visuo-motor adaptation. In a recent study, we showed that a single, brief PA exposure modulated neuronal activity yielded by a visual detection task by increasing the activation in the left inferior parietal lobule (IPL) and decreasing it in the right inferior parietal region for the whole visual field in a group of normal subjects (Crottaz-Herbette et al., 2014). However, the increased activation in the left IPL following PA was greater when the stimuli to be detected were presented in the left rather than in the central or right visual field, suggesting a reversal of the right hemispheric dominance for visual space processing after PA. Taking into account that PA-related modulation involved regions in the left IPL typically spared in neglect patients and that modulation increased the competence of the left hemisphere for the left visual space, one could expect that the left IPL, or more generally the left homologue of the right-lateralized ventral attentional network, underlies the beneficial effect of PA in neglect.

The beneficial effects of PA in neglect have been investigated in two neuroimaging studies. A PET study highlighted a significant correlation between PA-induced improvement in the performance on the Behavioural Inattention Test and increase in regional cerebral blood flow in the right cerebellum, the left thalamus, the left temporo-occipital cortex, the left medial temporal cortex and the right posterior parietal cortex (Luauté et al., 2006). Although the significant contribution of the left hemisphere, which was revealed in this study, could be interpreted as a result of PA-induced shift of the ventral attentional system from the right to the left hemisphere, this study does not provide any direct evidence. An fMRI study reported PA-induced changes in activation patterns to visuo-spatial tasks; line bisection and visual search, but not visual short-term memory. These changes corresponded to an increased neural activity bilaterally within the occipito-parieto-frontal cortex, predominantly within the superior parietal lobules (Saj et al., 2013). Line bisection and visual search are known to depend on the dorsal attentional network in normal subjects (Baumgartner et al., 2013; Leonards et al., 2000) and in neglect PA has indeed enhanced the involvement of the dorsal attentional system in these two tasks (Saj et al., 2013). The PA-induced involvement of the dorsal attentional system may be the result of the shift of the ventral attentional system to the left hemisphere (as discussed in Clarke and Crottaz-Herbette, 2016), but the study of Saj et al. did not address this issue.

Taken together, the above discussed evidence suggests that the effect of PA in neglect is accompanied by a change in the representation of the left visual space, in particular its enhancement within the left homologue of the right-lateralized ventral attentional system (Crottaz-Herbette et al., 2014; Clarke and Crottaz-Herbette, 2016). The issue has not been addressed in previous studies of PA effect in neglect (Luauté et al., 2006; Saj et al., 2013). The present study is based on the hypothesis that the effect of PA in neglect is accompanied by a change in the representation of the left visual space, in particular its enhancement within the left homologue of the right-lateralized ventral attentional system. To test this hypothesis, we conducted an event-related fMRI study with a target detection paradigm in neglect patients and compared them to age-matched controls.

2. Materials and methods

To assess the effect of PA in neglect patients and age-matched controls, we used the same experimental approach from our previous study (Crottaz-Herbette et al., 2014). A brief PA session was preceded and followed by event-related fMRI sessions using a detection task of targets within the right, central or left visual space. The activation patterns before and after PA were compared across groups. We have used rightward deviating prisms, as used in neglect rehabilitation. In this context, PA requires subjects to point towards visual targets with one hand while wearing prismatic lenses that deviate the visual field to the right (Pisella et al., 2006). After prism removal, pointing errors occur with overshoot to the left; this after-effect reflects prism-induced sensorimotor realignment (Weiner et al., 1983).

2.1. Participants

Twenty-six participants were included in this study: 15 patients with right hemispheric damage (8 women; mean ± SEM age: 55 ± 8 years) and 11 control subjects without history of neurological or psychiatric illness (7 women; mean age: 53 ± 7 years). Both groups were age-matched ($t = 0.77$; $p = 0.45$). All participants were right handed (Oldfield, 1971), and all had normal visual fields and normal or corrected-to-normal visual acuity. The participants provided written informed consent according to procedures approved by the Ethics Committees of the Faculty of Biology and Medicine, University of Lausanne and Canton de Vaud. Patients were recruited among the inpatients or outpatients treated by the Neuropsychology and Neurorehabilitation Service at the CHUV or the Lavigny Institution. Inclusion criterion included a first unilateral right hemispheric stroke (Table 1). Exclusion criteria included age outside the 20–70-year bracket; visual field defect; and/or major behavioural deficits which would preclude participation in the experimental paradigm. All patients underwent standard multidisciplinary rehabilitation during their hospitalization. A detailed neuropsychological evaluation was carried out at the time of the fMRI investigation, including neglect assessment with a full, standardized battery (Azouvi et al., 2006) and activities of daily living (Azouvi et al., 2003). The extent and location of lesions were analysed on structural MRI scans (Fig. 1).