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Neglect rehabilitation by prism adaptation: Different procedures have different impacts

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ABSTRACT

Several studies point to prism adaptation as an effective tool for the rehabilitation of hemispatial neglect. However, some recent reports failed to show a significant amelioration of neglect after prism adaptation as compared to control treatments. This apparent contradiction might reflect important differences in the procedures used for treatment. Here we compare the effects of two treatments (performed for 10 sessions, over 2 weeks) in two groups of patients, based either on a Terminal (TPA) or a Concurrent (CPA) prism adaptation procedure. During TPA only the final part of the pointing movement is visible and prism adaptation relies most strongly on a strategic recalibration of visuomotor eye–hand coordinates. In contrast, during CPA the second half of the pointing movement is visible, and thus adaptation mainly consists of a realignment of proprioceptive coordinates.

The present results show that both TPA and CPA treatments induced a greater improvement of neglect as compared to a control treatment of pointing without prisms. However, neglect amelioration was higher for patients treated with TPA than for those treated with CPA. At the same time, the TPA treatment induced a stronger deviation of eye movements toward the left, neglected, field as compared to the CPA treatment. Interestingly, in TPA patients the visuomotor and oculomotor effects of the treatment were directly related to the patients' ability to compensate for the optical deviation induced by prism during pointing (i.e., Error reduction effect).

In summary, prism adaptation seems particularly effective for the recovery of visuo-spatial neglect when conducted with a procedure stressing a correction of visuomotor eye–hand coordinates, i.e., with a TPA procedure. The present observations may help to better understand the mechanisms underlying prism-induced recovery from neglect and the procedural basis for some of the contradictory results obtained when using this rehabilitative strategy.

1. Introduction

Unilateral spatial neglect ('neglect') is a failure to report, respond, or orient to stimuli that are presented contralateral to a brain lesion (Heilman & Valenstein, 1979). Neglect symptoms range from a slowing of responses to contralesional stimuli to a complete lack of awareness of the contralesional half of space, at which point, patients behave as if that half of the world does not exist. A left neglect syndrome is frequently observed in right brain-damaged patients and is often severe enough to constitute a major handicap (Buxbaum et al., 2006; Denes, Semenza, Stoppa, & Lis, 1982; Milner & McIntosh, 2005). Thus, a rehabilitation protocol that would ameliorate neglect symptoms would also have a great impact on clinical outcome. In this respect, prism adaptation seems a particularly promising rehabilitative procedure (see Chokron, Dupierrix, Tabert, & Bartolomeo, 2007; Luaute, Halligan, Rode, Rossetti, & Boisson, 2006a; Luaute, Halligan, Rode, Jacquin-Courtois, & Boisson, 2006b; Pisella, Rode, Farne, Tilikete, & Rossetti, 2006; Rode, Klos, Courtois-Jacquin, Rossetti, & Pisella, 2006; Striemer & Danckert, 2010, for reviews), since this technique has been shown to produce some improvement in a wide range of neglect symptoms in the visual (e.g. Farne, Rossetti, Toniolo, & Ladavas, 2002; Frassinetti, Angeli, Meneghello, Avanzi, & Ladavas, 2002; Rode, Rossetti, & Boisson, 2001; Rode, Pisella, Rossetti, Farne, & Boisson, 2003; Rossetti et al., 1998; Serino, Angeli, Frassinetti, & Ladavas, 2006; Serino, Bonifazi, Pierfederici, & Ladavas, 2007; Serino, Barbiani, Rinaldesi, & Làdavas, 2009), somatosensory (Dijkerman, Webeling, ter Wal, Groet, & van Zandvoort, 2004; Maravita et al., 2003; Tilikete et al., 2001) and auditory (Jacquin-Courtois et al., 2010) domains. Repeated sessions

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of prism adaptation over two weeks induce a long-lasting improvement not only in standard clinical tests of neglect but also in more ecological measures (Frassinetti et al., 2002; Jacquin-Courtois, Rode, Pisella, Boisson, & Rossetti, 2008; Shiraishi, Yamakawa, Itou, Muraki, & Asada, 2008).

The prism adaptation procedure consists of the repetition of a series of pointing movements while wearing prismatic lenses that shift the visual field toward the right. To compensate for this optical displacement, the patient has to orient his/her pointing movement toward the left of visual space, resulting in a leftward drift of sensorimotor coordinates. The beneficial effects of prism adaptation on several neglect symptoms shows that visuomotor adaptation can modify high-level spatial representations, suggesting a direct link between plasticity of the sensorimotor system and space representation.

Despite the positive results obtained in many studies, some authors did not find a significant amelioration of neglect symptoms after prism adaptation (e.g. Nys, de Haan, Kunneman, de Kort, & Dijkerman, 2008; Rousseaux, Bernati, Saj, & Kozlowski, 2006; Turton, O'Leary, Gabb, Woodward, & Gilchrist, 2009). However, these contradictory results may be due to procedural differences in the prism adaptation procedures used by different laboratories. These procedural differences, and their possible impact on the recovery of neglect, are examined here within the context of their ability to induce plasticity in sensorimotor and spatial representations.

Recent findings from our laboratory have shown that visuomotor training consisting of pointing toward visual stimuli even without wearing prismatic goggles (i.e., neutral pointing) induced a moderate improvement of neglect symptoms. However, the improvement was significantly stronger and became clinically relevant (i.e., above the cut-off scores) when the pointing was performed during prism adaptation. The finding of an improvement after neutral pointing seems surprising, but can be easily explained in light of a form of visuomotor training embedded in the neutral pointing procedure. Pointing itself requires the patient to plan and perform a series of movements toward a visual stimulus placed in different positions of space. Manual pointing relies on a form of visuomotor coordination between the hand and eye (Henriques, Medendorp, Khan, & Crawford, 2002; see Crawford, Medendorp, & Marotta, 2004 and Buneo & Andersen, 2006 for reviews). Thus, the neutral pointing procedure trains the patient to orient the sensorimotor system toward the left side of space when a visual stimulus is presented there. If the orienting behaviour is reinforced by repetition of the procedure, the neutral pointing training might result in a long-term amelioration of neglect.

Prism adaptation can strengthen this type of visuomotor exercise, tapping into a similar synergy between the hand and eye. In addition to neutral pointing, prism adaptation also induces a systematic shift of visuomotor coordinates toward the left. Prismatic lenses indeed create a shift of the visual field toward the right side, as demonstrated by an initial *rightward* error in pointing to the visual target. The error signal is codified in visual eye-centred coordinates as the distance between the finger and the target in terms of visual angle. If patients are given visual feedback, after a few trials they will make a corrective movement to the target to compensate for this error and will progressively modify hand movement plans to reduce the target-finger gap. In this way, visual hand-centred coordinate systems may be reset by subtracting the visual error signal from the coordinates of the actual target signal (Redding & Wallace, 1993). As a consequence, the initial error in the visuomotor behaviour is corrected through visuomotor adaptation, and the visuomotor system resets toward the left. Since there is evidence that, during pointing, eye movements are yoked to hand movements and vice versa (Neggers & Bekkering, 2000; Prablanc, Echallier, Komilis, & Jeannerod, 1979; van Donkelaar, 1997), it has been hypothesized that under prism exposure, due to eye–hand coordination, the leftward deviation of hand movements also induces a leftward deviation of the oculomotor system (Angeli, Meneghello, Mattioli, & Ladavas, 2004; Ferber, Danckert, Joanisse, Goltz, & Goodale, 2003) and a consequent shift of visual attention toward the left side of the visual field, thus mediating the recovery of visual neglect. This hypothesis has been supported by showing an increase in the amplitude of the first leftward saccade after prism adaptation (Angeli et al., 2004) and a correlation between the correction of the pointing error during prism adaptation (i.e., Error reduction), the first saccade deviation and the amelioration of neglect obtained after the treatment (Serino et al., 2006).

The hypothesis that neglect recovery by prism adaptation is mediated by the oculomotor system was raised by those authors (Angeli et al., 2004; Frassinetti et al., 2002; Serino et al., 2006, 2009) who used a prism adaptation procedure with terminal exposure, i.e., very late visual feedback in target pointing. When the pointing movements are hidden until the final part of the movement when the index finger emerges, the pointing error during prism exposure is usually reliably high and the target-finger gap can be reduced only after a consistent amount of practice. Instead, in the concurrent (or early) exposure condition, i.e., when the limb is visible throughout the latter half of the pointing movement, the final pointing error is small and the target-finger gap can be reduced in the very first trials of practice. Because of the different visual feedback provided during pointing, terminal and concurrent exposure procedures vary for the coordinates system principally involved in the adaptation mechanisms, being primarily visual for the terminal exposure procedure and primarily proprioceptive for the concurrent exposure procedure (Redding, Rossetti, & Wallace, 2005). As a consequence, the terminal exposure procedure might produce a greater systematic leftward deviation of hand- and eye-centred reference frames and therefore a stronger effect on the oculomotor system and a stronger amelioration of neglect than the concurrent exposure procedure. Most of the studies on neglect recovery by prism adaptation have employed a concurrent exposure procedure (Berberovic, Pisella, Morris, & Mattingley, 2004; Farne et al., 2002; Ferber et al., 2003; McIntosh, Rossetti, & Milner, 2002; Morris et al., 2004; Nys et al., 2008; Rode et al., 2001; Rossetti et al., 1998; Rousseaux et al., 2006), whereas a minority of studies have used a terminal exposure procedure (Angeli et al., 2004; Frassinetti et al., 2002; Serino et al., 2006, 2007, 2009; Vangkilde & Habekost, 2010). Remarkably, in the latter studies, a long lasting amelioration of neglect was seen. Thus, it is possible to hypothesize that the different mechanisms of adaptation to prisms promoted by the two procedures are responsible for the different effects of treatment of neglect amelioration (see also Redding & Wallace, 2006; Striemer & Danckert, 2010).

Thus, the critical question is not simply whether remediation occurs after prism adaptation, but whether the leftward recalibration induced by a terminal exposure procedure is greater and more effective in ameliorating neglect than that induced by a concurrent exposure procedure. To this aim, in the present study, we directly compare the effects of two prism adaptation treatments, one based on terminal exposure procedure and the other based on concurrent exposure procedure. The results were compared with that of a treatment based on pointing with neutral goggles, in order to distinguish the specific effects of prism adaptation from those of a general visuomotor training provided by neutral pointing.

Thirty neglect patients were pseudo-randomly divided into 3 groups and assigned to terminal prism adaptation (TPA), concurrent prism adaptation (CPA), or neutral pointing (NP) procedures. All the treatments consisted of 10 daily sessions (5 sessions per week). Each session comprised 90 pointing movements toward a visual target presented in a variety of positions on the right, left, and at the centre of the visual field. Throughout the sessions, patients in