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Prism adaptation contrasts perceptual habituation for repetitive somatosensory stimuli

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ABSTRACT

Prism adaptation (PA) is a non-invasive procedure that requires performing a visuo-motor pointing task while wearing prism goggles inducing a visual displacement of the pointed target. This procedure involves a reorganization of sensorimotor coordination, and induces long-lasting effects on numerous higher-order cognitive functions in healthy volunteers and neglect patients. Prismatic displacement (PD) of the visual field can be induced when prisms are worn but no sensorimotor task is required. In this case, it is unlikely that any subsequent reorganization takes place. The effects of PD are short-lived in the sense that they last as long as prisms are worn. In this study we aimed, to the best of our knowledge for the first time, at investigating whether PA and PD induce changes in the perception of intensity of nociceptive and non- nociceptive somatosensory stimuli. We induced, in healthy volunteers, PD (experiment 1), or PA (experiment 2) and asked participants to rate the intensity of the stimuli applied to the hand undergoing the visuo-proprioceptive conflict (experiment 1) or adaptation (experiment 2). Our results indicate that: 1) the visuo-proprioceptive conflict induced by PD does not reduce the perceived intensity of the stimuli, 2) PA prevents perceptual habituation for both nociceptive and non-nociceptive somatosensory stimuli. Moreover, to investigate the possible underlying mechanisms of the effects of PA we conducted a third experiment in which stimuli were applied both at the adapted and the non-adapted hand. In line with the results of experiment 2, we found that perceptual habituation was prevented for stimuli applied onto the adapted hand. Moreover, we observed the same finding for stimuli applied onto the non-adapted hand. This result suggests that the detention of habituation is not merely driven by changes in spatial attention allocation. Taken together, these data indicate that prisms can affect the perceived intensity of somatosensory stimuli, but only when PA is induced.

1. Introduction

Prism adaptation (PA) is a non-invasive procedure that requires performing a visuo-motor pointing task while wearing prism goggles inducing a visual displacement of the pointed target. During PA, participants are asked to perform rapid pointing movements towards a target in front of them while wearing prisms, shifting the field of view sideways. Initially (early exposure phase), the prisms induce a pointing error towards the side of the optical shift (i.e. right-shifting prisms induce a rightward error). After some trials (late exposure phase), adaptation occurs: The pointing movements regain precision, indicating that the brain has recalibrated visuo-motor coordination by accounting for the shift in visual information produced by the prisms (reviewed in Jacquin-Courtois et al., 2013). This new visuo-motor alignment leads, when goggles are removed, to the so-called *after-effects* of PA. When participants are asked to point again to the target, an error in opposite direction to the visual displacement is observed (e.g. left-shifting prisms induce a rightward after-effect).

PA has been considered as a bottom-up procedure in the sense that, by operating at the low-level of sensorimotor coordination, it induces indirect effects on higher-level cognitive functions (Jacquin-Courtois et al., 2010; Rode, Rossetti, Li, & Boisson, 1998).

Prisms have also been used in healthy volunteers to modulate higher-order cognitive functions: for instance, PA is capable of affecting time perception (Frassinetti, Magnani, & Oliveri, 2009) and haptic abilities (Girardi, McIntosh, Michel, Vallar, & Rossetti, 2004). In addition, leftward PA can induce changes in the perceived position of the body midline (Girardi et al., 2004). This is important, as it suggests that PA affects both space and body representations. Interestingly, it has been proposed that conflicts between space and body frames of reference (based on space and body representations) influence the processing of somatosensory non-nociceptive inputs (Shore, Spry, & Spence, 2002; Yamamoto & Kitazawa, 2001), see Heed & Azanon (2014) for a review.

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Participants performing a temporal order judgment task (TOJ), in which they receive stimuli on either hand and are requested to indicate which hand was stimulated first, need a longer time interval between the two stimuli to indicate the correct response when the hands are crossed as compared to when the hands are uncrossed. This effect is thought to be due to the conflict that crossing the hands creates between the localization of stimuli according to somatotopic (e.g. stimuli applied on the right hand are coded as 'right') and space-based coordinates (which take into account where the right hand is positioned in the space surrounding the body). Interestingly this conflict is observed not only for tactile, but also for nociceptive stimuli (Sambo et al., 2013), indicating that different sub-modalities of somatosensation (i.e. touch and nociception) rely on both somatotopic and space-based frames of reference to localize the stimuli onto the body (De Paepe, Crombez, Spence, & Legrain, 2014; Favril, Mouraux, Sambo, & Legrain, 2014).

Wearing prisms without performing any sensory-motor procedure leads to a prismatic displacement (PD) of visual inputs in space. In contrast with the effects of PA which persist after the removal of the goggles (the after-effects), the effects of PD only persist as long as the prisms are worn. Folegatti, de Vignemont, Pavani, Rossetti, & Farne (2009) observed that, during PD, reaction times to tactile stimuli slowed down. These effects were explained as a consequence of the modified (e.g. shifted) visual input which induced a conflict between the perceived and seen position of the hands. Indeed, when prisms are worn and participants look at their hand, they see their hand shifted as compared to the 'real' position. Previous studies have shown that modified visual inputs (induced by a visual distortion of body size, Mancini, Longo, Kammers, & Haggard, 2011; Moseley, Parsons, & Spence, 2008) modulate pain perception in healthy volunteers.

On these premises, it is possible that both PA and PD are capable of inducing changes in the processing of somatosensory stimuli, most likely operating via different mechanisms.

In this study we aimed at investigating: 1) whether PA and PD induce significant changes in the processing of nociceptive and non-nociceptive somatosensory stimuli in healthy volunteers, and 2) what the possible mechanisms underlying these effects are. Considering that PD can induce a conflict between the location of the hand as defined by vision and proprioception and that conflicts between visual and proprioceptive frames of reference can affect the perceived intensity of the stimuli (Gallace, Torta, Moseley, & Iannetti, 2011; Torta et al., 2013), we hypothesized that prismatic displacement would *reduce* the perceived intensity of the stimuli. This hypothesis was tested in experiment 1. We are not aware of previous studies that have addressed the effects of PA on the *perception* of somatosensory stimuli, however, data available on both neglect patients and healthy volunteers suggest that PA improves haptic abilities and tactile detection (Dijkerman, Webeling, ter Wal, Groet, & van Zandvoort, 2004; Girardi et al., 2004; Maravita et al., 2003; McIntosh, Rossetti, & Milner, 2002). Therefore, we hypothesized that PA would *increase* the perceived intensity of stimuli. This hypothesis was tested in experiment 2. Moreover, to the best of our knowledge, in this study we investigated, for the first time, whether PD and PA are capable of modulating the perception of *nociceptive* somatosensory inputs. The possibility that prisms influence in a similar fashion both sub-modalities of somatosensation is not straightforward considering that the afferent input conveyed by touch and nociception relays on different pathways, and evidence exists to support either possibility that PA and PD modulate similarly or differentially nociceptive and non-nociceptive stimuli (Gallace et al., 2011; Mancini, Longo, Canzoneri, Vallar, & Haggard, 2013; Torta, Legrain, & Mouraux, 2015).

Finally, we tested, in experiment 3, what might be the possible mechanisms through which PA affects somatosensory perception, and specifically, if PA effects can be explained by shifts in spatial attention. We hypothesized that if spatial attention was involved as the only mechanism modulating the perception, rightward after-effects, like those expected in our case, would result in a modulation of the perceived intensity only for stimuli applied onto the hand towards which after-effects were directed. As an alternative explanation, it is also possible that the effects 'expand' to stimuli applied to the other hand, indicating more 'generalized' effects of PA (for an in-depth discussion of the possible physiological and functional meaning of 'expansion' please refer to Jacquin-Courtois et al. (2013)).

2. Methods

2.1. Participants

A total of 41 participants took part in this study. Thirteen volunteers (7 women, age 27.6 $\pm$ 4.6) participated in experiment 1, fifteen in experiment 2 (8 women, age 24 $\pm$ 3.1), thirteen in experiment 3 (6 women, age 27.6 $\pm$ 8.6). Participants were all right-handed by self-report with the exception of two volunteers in experiment 2. Before the beginning of the experiment, participants provided written informed consent. The experiment conformed to the Declaration of Helsinki rules and was approved by local ethics committee.

2.2. Stimuli and general experimental procedure

In all experiments, which were conducted in the same, dimly lit room, we used nociceptive and non-nociceptive somatosensory stimuli. All stimuli consisted in 0.5 ms constant current square-wave electrical pulses delivered through a computer-controlled DS7 Stimulator (Digitimer Ltd., UK). *Non-nociceptive somatosensory stimuli* were transcutaneous electrical stimuli (TES) delivered through two electrodes (0.5 cm diameter, 2 cm inter-electrode distance) placed at the wrist, over the superficial radial nerve. Two intensities of stimulation were used: 2 and 2.5 times the absolute individual detection threshold. Stimuli were never reported as painful. *Nociceptive stimuli* were intra-epidermal electrical stimuli (IES) applied at the hand dorsum with a stainless steel concentric bipolar needle electrode, made of a needle cathode (length, 0.1 mm; Ø, 0.2 mm) surrounded by a cylindrical anode (Ø, 1.4 mm) (Inui et al., 2002; Mouraux, Iannetti, & Plaghki, 2010). To modify the perceived intensity of the stimuli, we delivered trains of either 4 or 5 stimuli each lasting 500 μs, with an interstimulus interval of 10 ms. When low intensities are used (e.g. twice the detection threshold), IES can selectively activate nociceptive Aδ afferents, most likely type II mechano-heat sensitive fibers (Mouraux et al., 2010; Mouraux, Marot, & Legrain, 2014).

Detection thresholds were estimated on the stimulated hand (the right one in experiments 1 and 2, left and right ones in experiment 3) for both nociceptive and non-nociceptive somatosensory stimuli, prior the beginning of the experiment using the method of limits (Gescheider, 1997). A short familiarization phase was performed before each experiment, during which 10 stimuli of each modality and intensity were applied. During the experiment, participants had to rate verbally the intensity of each stimulus on a numerical rating scale (NRS) ranging from 0 (no sensation) to 100 (the maximal imaginable sensation for that kind of stimulus). Ratings were obtained in an interval ranging from 3 to 6 s after the administration of the stimulus. Participants were encouraged to be consistent in ratings within the same modality, but they were allowed to change the scale across modalities. An 'intensity' rather than a 'pain' scale was used for IES because these stimuli, despite being able to selectively activate Aδ nociceptive fibers when used at low intensities (Legrain & Mouraux, 2013), are not always reported as painful. Indeed, the term nociception describes a stimulus capable of activating nociceptors regardless of whether it is associated with a perception of pain.

During all experiments, participants sat at a table with their right hand (experiments 1 and 2) or right and left hand (experiment 3) positioned beneath a wooden frame covered by a semi-silvered mirror. In experiment 1, the lights under the wooden frame were switched on to allow vision of the hand during stimulation (see below for additional