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PASSIVE OR SIMULATED DISPLACEMENT OF ONE ARM (BUT NOT ITS MIRROR REFLECTION) MODULATES THE INVOLUNTARY MOTOR BEHAVIOR OF THE OTHER ARM

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Abstract—Recent studies of both healthy and patient populations have cast doubt on the mirror paradigm's beneficial effect on motor behavior. Indeed, the voluntary arm displacement that accompanies reflection in the mirror may be the determining factor in terms of the motor behavior of the contralateral arm. The objective of the present study was to assess the respective effects of mirror reflection and arm displacement (whether real or simulated) on involuntary motor behavior of the contralateral arm following sustained, isometric contraction (Kohnstamm phenomenon). Our results revealed that (i) passive displacement of one arm (displacement of the left arm via a motorized manipulandum moving at 4°/s) influenced the velocity of the Kohnstamm phenomenon (forearm flexion occurring shortly after the cessation of muscle contraction) in the contralateral arm and (ii) mirror vision had no effect. Indeed, the velocity of the Kohnstamm phenomenon tended to be adjusted to match the velocity of the passive displacement of the other arm. In a second experiment, arm displacement was simulated by vibrating the triceps at 25, 50 or 75 Hz. Results showed that the velocity of the Kohnstamm phenomenon in one arm increased with the vibration frequency applied to the other arm. Our results revealed the occurrence of bimanual coupling because involuntary displacement of one arm was regulated by muscle-related information generated by the actual or simulated displacement of the other arm. In line with the literature data on voluntary motor behavior, our study failed to evidence an additional impact of mirror vision on involuntary motor behavior.

Key words: mirror paradigm, bimanual coupling, Kohnstamm phenomenon, muscular afferents.

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Abbreviations: ANOVA, analysis of variance; iEMG, integrated EMG values; MVC, maximum voluntary contraction.

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INTRODUCTION

Over the last 10 years, the mirror paradigm has been considered as a treatment option for restoring brain function in general (Rosen and Lundborg, 2005; Dohle et al., 2009; Ramachandran and Altschuler, 2009) and promoting recovery from hemiparesis and hemiplegia in particular. In this mirror paradigm, the participant sits in front of a mirror oriented parallel to the body midline, with its reflective surface facing one limb and blocking the view of the other. When looking into the mirror, the participant sees the reflection of one limb which position coincides with that of the other (unseen) limb. This arrangement can create vivid visual illusions whereby movement of an intact limb in hemiparetic patients may be perceived as affecting the paretic (unseen) limb. However, after early enthusiasm for mirror therapy, the true benefit of this approach (notably when compared with therapies such as bimanual coupling) in recovery from hemiparesis is now being questioned (for a review, see Rothgangel et al., 2011).

Metral et al. (2014) recently assessed the mirror paradigm's role in the motor control of bimanual coordination tasks performed by healthy participants during sensorimotor disturbance in four visual conditions (i) mirror vision (i.e. with the non-dominant arm reflected in a mirror and the dominant arm hidden), (ii) full vision (i.e. both arms visible), (iii) with only the non-dominant arm visible and (iv) with the eyes closed. The participants were required to produce synchronous movements of both arms while sensorimotor disturbance was applied to their dominant arms (co-vibration of antagonistic muscles – the biceps and the triceps). This disturbance substantially decreased the sensitivity of position perception (Roll et al., 1989; Bock et al., 2007) and altered the subject's ability to perform coordinated visuomotor or postural tasks (Gilhodes et al., 1986; Oullier et al., 2009) and bimanual coupling, that is, coupling between the two hands constrained in spatial or temporal terms (Swinnen, 2002; Swinnen et al., 2003). Although mirror reflection of one arm can induce consistent, vivid, perceptual illusions (Holmes et al., 2004; Zampini et al., 2004; Mercier and Sirigu, 2009; Ramachandran and Altschuler, 2009; Guerraz et al., 2012; Metral et al., 2013), Metral et al.'s (2014) results confirmed that mirror vision is not highly effective in modulating voluntary motor behavior. Indeed, although performance in synchronous movements was higher in the condition of mirror vision as compared to vision of only the non-dominant arm, the motor performance was no better in the mirror vision condition than in the eyes-closed condition – regardless of whether or not sensorimotor disturbance was applied. In contrast, full vision of the two hands facilitated synchronous movements in the condition of sensorimotor disturbance.

The fact that it is difficult to demonstrate mirror vision's impact on voluntary, bimanual, coordinated movements does not imply that mirror vision has no effect (or a limited effect) on motor control as a whole. Hence, the objective of the present study was to further investigate the mirror paradigm's impact on motor control in the context of involuntary (rather than voluntary) motor behavior. After performing an intense, long-lasting, isometric muscle contraction, involuntary movements may occur as a consequence of post-contraction muscle activity (Craske and Craske, 1986; Gurfinkel and Levick, 1989; Ghafouri et al., 1998; Ivanenko et al., 2006; Duclos et al., 2007). This phenomenon was first described by Kohnstamm in 1915. It can be easily experienced by strongly pushing or pulling with the arms against a fixed support for half a minute. Shortly after the cessation of isometric muscle contraction, the arms rise slowly and involuntarily – giving a feeling of lightness. This phenomenon is thought to be related to both peripheral components (increased afferent inflow after sustained contraction; see Gregory et al., 1987; Hagbarth and Nordin, 1998) and central components (prolonged excitation of central structures; see Duclos et al., 2007). Dissociating actual and perceived body position (and therefore manipulating body representation) has been shown to modulate this involuntary motor behavior. Wells (1944) used the Kohnstamm phenomenon (which can also occur in the legs) to demonstrate the influence of somesthetic inputs from the neck on limb muscles in humans and showed that the extension of the knee joints following sustained isometric contraction becomes asymmetric when the head is turned toward one shoulder. Interestingly, Gurfinkel and Levick (1991) showed that modulation of the Kohnstamm phenomenon occurred regardless of whether the head's postural changes were actual or only perceived; dissociation was achieved by vibration of neck muscles, hypnosis or use of a return phenomenon. Considering that the mirror paradigm is an easy way to dissociate actual and perceived arm position, we set out to modulate the Kohnstamm phenomenon in one arm (the right arm) by using a mirror to provide participants with a false visual representation of that arm. After a long-lasting isometric contraction of the biceps of the right (unseen) arm, participants were required to look at their left arm and its reflected image through a mirror positioned in the sagittal plane. The left arm was either static or moved passively by a motorized manipulandum.

The results of this first experiment (referred to as Experiment 1) revealed that (i) passive displacement of the left arm clearly modulated the kinematics of the involuntary right arm displacement following effort (i.e. Kohnstamm phenomenon) and (ii) unexpectedly, mirror manipulation had no additional effect. To determine whether proprioceptive input generated by passive displacement of the left arm might be responsible for the modulation of the contralateral post-contraction, a second experiment was performed. Passive displacement of the left arm was replaced by simulated displacement of that same arm via the use of vibratory stimulation (Goodwin et al., 1972; Gilhodes et al., 1986). Our results showed that vibratory simulation of arm movement modulated the kinematics of the Kohnstamm phenomenon in the same way as passive displacement did.

EXPERIMENTAL PROCEDURES OF EXPERIMENT 1

Participants

Twelve participants (7 females and 5 males; mean (SD) age = 22.1 (2.3) years) took part in Experiment 1. All but one were right-handed (as determined in the Edinburgh Inventory Test – Oldfield, 1971). As reported in the literature, some individuals do not show the Kohnstamm phenomenon (Craske and Craske, 1986; Gurfinkel and Levick, 1991; Ivanenko et al., 2006), and so we screened the participants for the Kohnstamm phenomenon in a preliminary experiment. Twelve of the 17 screened participants displayed the Kohnstamm phenomenon on the first application and therefore took part in Experiment 1. None of the 12 volunteers had a history of visual, proprioceptive or neuromuscular disease, and all provided their prior, written, informed consent to participation in the experiment. The experiment was performed in accordance with the tenets of the Declaration of Helsinki and the study protocol had been approved by the local independent ethics comity (Ethics comity LLSH, Chambery, France).

Material

Participants sat in front of a large, custom-built box. Depending on the experimental conditions, either an opaque board (measuring 65 by 65 cm and preventing the participant from directly viewing his/her right hand) or a mirror (measuring 65 by 65 cm) with the reflective surface facing toward the participant's left was positioned vertically in the middle of the box and was oriented parallel to the participant's mid-sagittal plane. The participants' forearms were positioned on each side of the mirror (or opaque board) and were held by two manipulanda devices (wooden arms on which subjects placed their forearms and hands) positioned at 30° to the horizontal in the starting position (Fig. 1). The distances between the manipulanda and the mirror were adjusted so that the mirror image of the left arm coincided with the position of the right arm. The right manipulandum was fixed, whereas the left manipulandum was motorized (with a low-noise direct current motor) and could rotate (via a remote controller) to flex the participant's left elbow joint. The participant's forearms were adjusted on the manipulandum so that the axis of motorized rotation coincided exactly with the elbow joint.