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Influence of head orientation on visually and memory-guided arm movements

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ABSTRACT

In the absence of visual supervision, tilting the head sideways gives rise to deviations in spatially defined arm movements. The purpose of this study was to determine whether these deviations are restricted to situations with impoverished visual information. Two experiments were conducted in which participants were positioned supine and reproduced with their unseen index finger a 2 dimensional figure either under visual supervision or from memory (eyes closed). In the former condition, the figure remained visible (using a mirror). In the latter condition, the figure was first observed and then reproduced from memory. Participants' head was either aligned with the trunk or tilted 30° towards the left or right shoulder. In experiment 1, participants observed first the figure with the head straight and then reproduced it with the head either aligned or tilted sideways. In Experiment 2, participants observed the figure with the head in the position in which the figure was later reproduced. Results of Experiment 1 and 2 showed deviations of the motor reproduction in the direction opposite to the head in both the memory and visually-guided conditions. However, the deviations decreased significantly under visual supervision when the head was tilted left. In Experiment 1, the perceptual visual bias induced by head tilt was evaluated. Participants were required to align the figure parallel to their median trunk axis. Results revealed that the figure was perceived as parallel with the trunk when it was actually tilted in the direction of the head. Perceptual and motor responses did not correlate. Therefore, as long as visual feedback of the arm is prevented, an internal bias, likely originating from head/trunk representation, alters hand-motor production irrespectively of whether visual feedback of the figure is available or not.

1. Introduction

A functional association between head and hand/arm sensorimotor systems has been well demonstrated in sensorimotor tasks such as pointing towards remembered targets (Berger et al., 1998; Bresciani et al., 2002), drawing geometric figures (Guerraz, Blouin, & Vercher, 2003), arm pointing adaptation (Seidler, Bloomberg, & Stelmach, 2001) or even haptic adjustments (Kerkhoff, 1999; Guerraz, Luyat, Poquin, & Ohlmann, 2000; Luyat, Gentaz, Corte, & Guerraz, 2001). An effective way to investigate such a functional association with these tasks involves dissociating head and trunk orientations during the movement. Using this procedure, Guerraz et al. (2003) have shown that tilting the head towards a shoulder induces an overall rotation of the hand-drawn reproductions in the opposite direction to head tilt. Interestingly, when the gravitational cues are no longer present or relevant to the task (e.g. when performing the arm movement in the supine posture or in microgravity), deviations increase markedly (Berger et al., 1998; Guerraz et al., 2000, 2003). These findings therefore provide evidence for the importance of gravitational and neck afferent cues in the control of hand/arm movement in space.

The errors observed in both the pointing and drawing tasks when the participant's head is tilted sideways could indicate a bias in the internal representation of body configuration. This hypothesis is in line with the observations made by Knox and collaborators that rotation of the head towards the shoulder alters the perception of arm position (Knox & Hodges, 2005; Knox, Cordo, Skoss, Durrant, & Hodges, 2006). The errors induced by tilting the head on the trunk, which are usually in the opposite direction to the tilt, might reveal an over-estimation of the angle between the head and the trunk. Such misperception would be particularly prejudicial in sensory-impoverished contexts (absence of pertinent visual or gravitational cues) in which the trunk constitutes the main reference to control arm movement (Gurfinkel, Lestienne, Levik, Popov, & Lefort, 1993). It is worth noting that angular deviations in motor production would not be directly related to the orientation of the head relative to the trunk *per se* but rather to the conscious perception of head

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and body configuration (Knox et al., 2006, Mars, Honoré, Richard, & Coquery, 1998; Guerraz, Navarro, Ferrero, Cremieux, & Blouin, 2006).

In most of the aforementioned experiments, participants had the head aligned with the trunk and were first asked to inspect the position of the target (for reaching movements) or the contours of the geometric shape (for drawing movements) before closing their eyes. Then, participants had to wait for the orientation of their head to be dissociated from that of their trunk before either reaching the memorized target or reproducing the memorized shape (memory-guided action). Importantly, converging lines of evidence suggest that the availability of hand and target visual information has a strong influence on both the coding of target location and the control of spatially-oriented movements. For instance, the frame of reference (e.g., egocentric, allocentric) used to perform perceptivo-motor tasks is known to be a function of the type of visual information available during the movement (Bridgeman, 1991; Paillard, 1991; Blouin et al., 1993). Moreover, visually-guided movements are usually more accurate than memory-guided movements (Prablanc, Pélisson, & Goodale, 1986; Hesse & Franz, 2009; Heath, Westwood, & Binsted, 2004; McIntyre, Stratta, & Lacquaniti, 1998; Westwood, Heath, & Roy, 2001; Sarlegna, Gauthier, Bourdin, Vercher, & Blouin, 2006). The increased accuracy is related to the amount of visual feedback provided to the participants. For instance, Schettino, Adamovich, and Poizner (2003) reported that the performance in a grasping task is higher when feedback of both the hand and target is provided compared with conditions where the participants can only see the target. However, participants' performance is higher in the latter condition than when no visual feedback is available. Finally, it has been shown that when sight of the target is occluded during the task, the delay between the visual presentation of the target and the onset of the reaching movement is a determinant factor of performance (Elliott, 1986; Hesse & Franz, 2009).

Within this framework, there are therefore reasons to believe that the effect of head tilt on the direction of the hand movements observed in previous studies could be limited to situations with impoverished visual information. Here we investigated this issue by having participants reproduce the contour of a geometric illustration with either the head aligned with the trunk or tilted towards a shoulder in different visual conditions: During the drawing movement, we prevented participants from seeing either both the illustration object and hand simultaneously (memory-guided) or only their moving hand (visually-guided). In the visually-guided task, as visual information of the illustration was available, the participant could update the properties of the geometric figure such as its shape or size during the drawing. In that respect, vision should be particularly beneficial for motor production as long as intrinsic characteristics of the object are concerned. Whilst being able to see the figure during the movement should allow participant to update their position relative to the figure, it should not however provide direct information relative to their body configuration. Whether this information would nevertheless be beneficial to the overall orientation of the motor production remains to be determined.

In addition to motor bias, tilting the head towards the shoulders induces perceptual illusions. For instance, when gravitational information is not relevant to the task, such as in the present study where participants were in a supine position, lines (*or objects*), which are oriented parallel to the trunk midline, are perceived as being tilted in the direction opposite to that of the head (Templeton, 1973, Parker, Poston, & Gulledge, 1983). Such perceptual illusion was evaluated in participants taking part in Experiment 1. However, because motor processes are largely immune to visual illusions (Aglioti, DeSouza, & Goodale, 1995; Bock, 1997; Glover & Dixon, 2001), we hypothesized that visually guided motor behaviour in condition of head tilt would not be correlated to the putative visual illusion induced by the head tilt.

2. Methods

2.1. Participants

Twelve and seven healthy participants took part in Experiments 1 and 2 respectively. Experiment 1 involved five women and seven men aged 19–32 years (mean 24.3, *SD* 3.5). Experiment 2 involved four women and three men aged 19–40 years (mean 26, *SD* 8.5) who did not take part to Experiment 1. They were all right handed according to the Edinburgh Inventory Test (Oldfield, 1971), naive to the aims of the study, and had no known history of vestibular, visual, or neuromuscular disease. Informed consent was obtained prior to the experiment according to the Declaration of Helsinki.

2.2. Procedure and apparatus

Participants were positioned supine on a thin mattress. Supine position (instead of seated position) was chosen to both minimize ocular-counter torsion which could have otherwise influenced the arm movement (see Ott, 1992; Wetzig & Baumgarten, 1990; Howard, 1986) and eliminate the contribution of the otoliths. A wooden board was positioned 50 cm above the participant in the horizontal plane (i.e., parallel to the participant's frontal plane). A mirror was placed at 45° between the participant's head and the board. The mirror reflected a geometric figure that was fixed on a board to the rear of the participant's head (see Fig. 1). The centre of the mirror was positioned at 40 cm from the geometric figure and at 40 cm from the participant's eyes. The use of a mirror allowed the participants to see the figure in the fronto-parallel plane at the level of their eyes without being able to see their hand. The figure represented a house composed of 5 luminescent segments (one horizontal line [the base], two verticals [the walls] and two segments oriented at 45° [the roof]). The base was 20 cm long. The remaining four segments were 14 cm long.

During the experiment, the lights in the experimental room were turned off so that only the luminescent object was visible to the participant. A device was used to position and secure the participant's head either aligned with the trunk or tilted 30° towards the left or right shoulder. Right index finger displacements were recorded in three dimensions with a Polhemus Fastrak. The receiver-coil of the 3-D magnetic sensor was fixed on the participant's fingertip. Output signals from the Fastrak were sampled at a rate of 120 Hz. As the figure to be drawn had two dimensions, only finger displacements in the horizontal plane were recorded.

2.3. The motor task

Participant's task was to reproduce the reflected geometric figure on the board above them using their right index finger without seeing their hand. The involvement of finger and wrist in drawing lines of such length has been shown to be minimal, the elbow and shoulder being the prime effectors for such movements (Lacquaniti, Ferrigno, Pedotti, Soechting, & Terzuolo, 1987). Nevertheless, in order to minimise large differences in the motor strategies between participants for line drawing, their wrist and index finger were secured in a fixed pointing position using a light splint. Prior to the experiment, subjects were required to familiarise themselves with the drawing task with the eyes open or closed. At the beginning of each trial, participants inspected the geometric figure for 10 s before receiving the instruction to position their index at the top of the right wall of the house and close their eyes. Then, the participant's head either remained aligned with the trunk (head-straight) or was slowly tilted by the experimenter towards the right (30°, head-right) or left (−30°, head-left) shoulder. After 10 s, participants were required to reproduce the figure either with their eyes closed (memory-guided condition) or with the eyes open (visually-guided condition). In the latter condition, the participants could only see the figure and had no