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Explicit and implicit knowledge of environment states induce adaptation in postural control

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HIGHLIGHTS

- Increased velocity of visual motion decreases coupling to visual information.
- Knowledge of visual surrounding manipulation reduces coupling to visual information.
- Implicit and explicit knowledge of environment states reduce sway amplitude.

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ABSTRACT

The aim of this study was to investigate the effects of explicit and implicit knowledge about visual surrounding manipulation on postural responses. Twenty participants divided into two groups, implicit and explicit, remained in upright stance inside a “moving room”. In the fourth trial participants in the explicit group were informed about the movement of the room while participants in the implicit group performed the trial with the room moving at a larger amplitude and higher velocity. Results showed that postural responses to visual manipulation decreased after participants were told that the room was moving as well as after increasing amplitude and velocity of the room, indicating decreased coupling (down-weighting) of the visual influences. Moreover, this decrease was even greater for the implicit group compared to the explicit group. The results demonstrated that conscious knowledge about environmental state changes the coupling to visual information, suggesting a cognitive component related to sensory re-weighting. Re-weighting processes were also triggered without awareness of subjects and were even more pronounced compared to the first case. Adaptive re-weighting was shown when knowledge about environmental state was gathered explicitly and implicitly, but through different adaptive processes.

1. Introduction

Our daily activities require the control of a stable and (at the same time) flexible upright stance. To achieve this, the nervous system must process a stimulus-rich and continuously changing environment, requiring the ongoing integration of multisensory information to update our estimate of self-motion. This integration process is related to the mechanism of sensory re-weighting, which is defined as the ability to select and decrease/increase the influence of a specific sensory stimulus on postural control (e.g., [3,13]).

Recently, sensory re-weighting has been rigorously demonstrated and uncovered by manipulating the amplitude and velocity of visual stimuli [1,8,18], vibrating ankle muscles [19], and/or changing somatosensory and visual cues simultaneously [17]. In all cases, changes in postural control were observed, that relied on the down- or up-weighting of the sensory cue's influence on balance (i.e. upright stance). This indicates that the central nervous system modulates the contribution of the available sensory cues

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based upon the reliability that they would furnish. Such a mechanism has been characterized as nonlinear and much research has been conducted to understand the mechanistic underpinnings of sensory re-weighting [7,9,10,16,20].

Sensory re-weighting in postural control responses has been observed when participants were told about forthcoming changes in sensory cues. Such instruction-based influences of knowledge on sensory re-weighting were first observed by Nashner and colleagues [6,12] and denominated as central settings adjustments of postural responses. In a more recent study, participants were told that a vision manipulation was occurring and subsequently down-weighted the influence of such sensory cue manipulation [4]. Nevertheless, evidences demonstrate that such down-weighting is stimulus-dependent [1].

Adaptation in postural control system regarding sensory re-weighting processes has also been observed after amplitude and velocity of visual motion were increased, leading to down-weighting of visual stimulus as well [2,8]. Specifically, it has been demonstrated that when the amplitude of the visual scene motion changes from low amplitude to high amplitude, the postural control system responds relatively quick. However, when the direction of the jump is reversed (from high to low) the response is significantly slower [8,14]. Therefore, the postural control system adapts rapidly the coupling to visual information through sensory reweighting processes when the amplitude of visual motion is high because this represents a threat to stability. In the case of low visual motion amplitude, since stability is not threatened the system can adjust its functioning slowly. Importantly, adaptation due to stimulus properties changes does not involve conscious, since individuals were never informed about visual manipulation [2,14].

Explicit knowledge about visual surrounding manipulation, acquired when individuals were informed about visual motion and asked to resist its influence, as well as implicit knowledge, acquired when participants were exposed to higher velocity and larger amplitude of visual motion without conscious knowledge of the manipulation, have been demonstrated to decrease coupling to visual information (e.g., [1,8]). While several studies provided evidence to confirm these two adaptation mechanisms, no study has ever investigated differences between these two processes with the purpose to discuss how attention and cognitive aspects related to postural control can affect sensory re-weighting compared to behaviors that occur implicitly, that is, without conscious mechanisms involved. Therefore, the purpose of this study was to compare the effects of implicit and explicit information about environmental state in the coupling between visual information and postural control. We employed the moving room paradigm [5,11,15,16] in which participants' task was to fixate a visual marker on the wall ahead of them and to maintain an upright stance, while the walls of the room moved sinusoidally on a stationary floor. Participants acquired knowledge of the room's movement either explicitly, by simply being told that the room was moving, or implicitly, by drastically changing the motion parameters of the room (amplitude and velocity), without informing participants about such a change.

2. Methods

2.1. Subjects

Twenty healthy young adults participated in this study, equally divided into two groups, one with explicit and one with implicit knowledge. The explicit group included eight males and two females (*M* = 22.3; *SD* = 1.57 years), whereas the implicit group four males and six females (*M* = 22.0; *SD* = 2.40 years). The recruited participants were undergraduate or graduate students and all had normal or corrected-to-normal vision. In addition, all of them gave their informed consent prior to participation according to procedures approved by the Institutional Review Board.

2.2. Procedures

Participants were asked to maintain upright stance inside a moving room at 1 m away from the frontal wall and to look at a target attached at this frontal wall. The moving room consisted of three walls and a roof (2.1 m long × 2.1 m wide × 2.1 m height), mounted on wheels so that it could be moved back and forth by a servomotor mechanism, while the floor remained motionless. The walls and the roof were white with black stripes painted on the walls, creating a pattern of 42 cm wide vertical white and 22 cm wide vertical black stripes. A 20-Watt fluorescent lamp was attached to the ceiling and used to maintain consistent light throughout data collection.

The servomotor mechanism consisted of a controller (Compumotor, Model APEX 6151), a controlled stepper motor (Compumotor, Model N0992GR0NMSN), and an electrical cylinder (Compumotor, Model EC3-X3xxN-10004a-Ms1-MT1M), which connected the servomotor to the moving room's structure. Specialized software (Compumotor, Motion Architect for Windows) controlled the servomotor mechanism, moving the room continuously away from and toward the participant (anterior/posterior direction).

A movement analysis system (OPTOTRAK 3020 – 3D Motion Measurement System) was placed behind the participants. One OPTOTRAK IRED marker was placed on the participant's back (at the 8th thoracic vertebra level) and another one on the frontal wall of the moving room. These markers provided information about the participant's trunk sway and the moving room's displacement, respectively, in the anterior–posterior, medial–lateral, and vertical directions, with a sampling rate of 100 Hz.

For each participant, 7 trials of 60 s were collected. The first three trials were named *pre-change*, and the room was oscillated with peak-to-peak amplitude of 0.5 cm, peak velocity of 0.6 cm/s, and frequency of 0.2 Hz. In the fourth trial, named *change* trial, different manipulations were applied to each group. In the explicit group, participants were verbally (explicitly) informed that the room was moving before the fourth trial started and were asked to resist to this movement (while the parameters of the room's movement remained the same as used in previous trials during the fourth trial). In the implicit group, the parameters of the room's movement were changed in the fourth trial to peak-to-peak amplitude of 3.5 cm and peak velocity of 3.5 cm/s. Importantly, no further verbal (explicit) information was given to the participants of the implicit group about the room's movement. In the remaining trials (Trials 5–7), named *post-change* trials, the room was oscillated using the same parameter values of the pre-change trials (Trials 1–3), i.e., with peak-to-peak amplitude of 0.5 cm and a peak velocity of 0.6 cm/s. Thus, the difference between the two groups was related to the change trial (Trial 4), in which the explicit group was told about the room's movement (with the oscillation parameters remaining the same), while the implicit group experienced a change in the oscillation parameter, but was not informed about the room's movement. When participants in the explicit group were informed about room movement, before the fourth trial, they were explicitly told that the room had been moving in the previous trials and would continue to move in the next trials during the entire experiment.

In order to assure participants would be unaware of the movement of the room at the beginning of the experiment, the wheels in which the room was mounted were covered in a way participants could not see them and a random sound (white noise) was used during the entire experiment to mask any possible sound produced by the motor that moved the room. None of the participants