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IMPROVING SPATIAL UPDATING ACCURACY IN ABSENCE OF EXTERNAL FEEDBACK

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Abstract—Updating the position of an earth-fixed target during whole-body rotation seems to rely on cognitive processes such as the utilization of external feedback. According to perceptual learning models, improvement in performance can also occur without external feedback. The aim of this study was to assess spatial updating improvement in the absence and in the presence of external feedback. While being rotated counterclockwise (CCW), participants had to predict when their body midline had crossed the position of a memorized target. Four experimental conditions were tested: (1) Pre-test: the target was presented 30° in the CCW direction from participant's midline. (2) Practice: the target was located 45° in the CCW direction from participant's midline. One group received external feedback about their spatial accuracy (Mackrous and Simoneau, 2014) while the other group did not. (3) Transfer T^{30}_{CCW}: the target was presented 30° in the CCW direction to evaluate whether improvement in performance, during practice, generalized to other target eccentricity. (4) Transfer T^{30}_{CW}: the target was presented 30° in the clockwise (CW) direction and participants were rotated CW. This transfer condition evaluated whether improvement in performance generalized to the untrained rotation direction. With practice, performance improved in the absence of external feedback ($p = 0.004$). Nonetheless, larger improvement occurred when external feedback was provided ($ps = 0.002$). During T^{30}_{CCW}, performance remained better for the feedback than the no-feedback group ($p = 0.005$). However, no group difference was observed for the untrained direction ($p = 0.22$). We demonstrated that spatial updating improved without external feedback but less than when external feedback was given. These observations are explained by a mixture of calibration processes and supervised vestibular learning.

Key words: vestibular, learning, calibration, generalization, human.

INTRODUCTION

To have a stable representation of the visual scene during body motion, such as walking, the spatial representation of visual stimuli must be updated. This is known as the spatial updating process. One important question is how sensory information, other than visual, contributes to updating objects' position during motion. Previous studies have demonstrated that, during passive motion in the dark, the main sensory information used to perform spatial updating when the eyes' motion is attenuated does originate from the vestibular apparatus (Israël et al., 1999; Li and Angelaki, 2005; Klier et al., 2008). However, interpreting vestibular signals in isolation from other sources of information (i.e., efference copy, neck proprioception or eye motion) alters the accuracy of spatial updating processes (Blouin et al., 1995). Nonetheless, in updating the position of a previously seen visual target during or after passive body rotation, performance accuracy is recovered under supervised learning processes, i.e., when practice and external feedback are provided (Israël et al., 1999; Ventre-Dominey and Vallee, 2007; Mackrous and Simoneau, 2011). This suggests that the ability to use vestibular signals for spatial updating relies on a perceptual learning mechanism that is governed by cognitive processes such as supervised learning. However, recent data suggested that improvement in spatial updating accuracy might be possible without external feedback (Mackrous and Simoneau, 2014). In that regard, some earlier studies conducted in other sensory domains (e.g., visual) have shown that, with repeated exposure to stimuli, perceptual learning occurred in the absence of external feedback (Fahle and Edelman, 1993; Herzog and Fahle, 1997; Petrov et al., 2006; Dosher and Lu, 2009). This process has been called unsupervised learning.

According to the Hebbian learning hypothesis (Hebb, 1949), unsupervised learning is independent of cognition such as the utilization of feedback. For instance, the ability to discriminate the orientation of a visual stimulus improves similarly with or without feedback (Petrov et al., 2006). Nonetheless, a pure unsupervised learning system cannot account for the observation that feedback enhances learning or is necessary to improve performance in some contexts (Shiu and Pashler, 1992; Fahle and Edelman, 1993). For that reason, a hybrid system that includes two components was proposed (Petrov et al., 2006); a supervised learning component that is dependent on cognitive process and an unsupervised learning component that is independent of cognitive process.

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Abbreviations: ANOVA, Analysis of variance; CCW, Counterclockwise; CW, clockwise; ETF, Earth-fixed target; MWU, Mann–Whitney U test; VOR, Vestibulo-ocular reflex.

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In the present experiment, we first assessed whether an improvement in spatial updating can occur without feedback and evaluated whether improvement, if any, relies on an unsupervised learning process. Participants had to predict the position of a previously seen earth-fixed target (EFT) while being passively rotated in the dark. In the absence of feedback, a pure supervised learning mechanism would fail to show any improvement in spatial updating. On the other hand, an unsupervised learning mechanism would be supported if learning occurred without feedback, whereas a hybrid version would be supported if learning occurred in the absence of feedback but was enhanced when feedback was provided. Furthermore, because there is some controversy regarding the generalization of perceptual learning (McGovern et al., 2012), we assessed whether improvement in spatial updating, if any, transfers to other target eccentricity or to the untrained direction.

EXPERIMENTAL PROCEDURES

Subjects

Fourteen healthy individuals between the ages of 20 and 30 years old participated in this study. None of them reported motor or sensory impairments. All participants gave written informed consent according to Université Laval's Biomedical Ethics Committee's guidelines and the study was conducted in accordance with the Declaration of Helsinki.

Task and apparatus

The participants were seated in a rotating chair facing a semicircular panel with a radius of 1.5 m in a completely dark room (Fig. 1a). They were secured to the chair with a 4-point belt system and chin support that prevented head movement relative to the trunk during rotation. During passive body rotation, participants were instructed to gaze at a chair-fixed target (i.e., red light-emitting diode) located at 1 m straight ahead at eye level and maintain fixation in order to attenuate the vestibulo-ocular reflex (VOR). Note that the use of a chin rest and a chair-fixed target attenuated efference copy and neck and eye muscle afferents as sources of information for spatial updating. The chair's angular position was measured with an optical encoder (US Digital, model H5S, Vancouver, WA, USA) fixed at the chair's center of rotation and monitored at 1000 Hz with a 16-bit A/D board (National Instruments Corporation, model AT-MIO-16DE-10, Austin, TX, USA). A light-emitting diode array placed behind the chair displayed the magnitude of chair rotation to be produced by the experimenter (i.e., the chair was manually rotated).

At the beginning of each trial, participants were first placed in the starting position and asked to gaze at the fixation point (i.e., red light-emitting diode) located straight ahead on the semicircular panel at eye level. This was made to ensure that visual peripheral EFT for a given eccentricity appeared at the same retinal position. Then, a visual peripheral EFT (red light-emitting diode on the semicircular panel) was illuminated for 1 s (Fig. 1 inset). Participants were asked to locate and memorize the position of the target without making a saccade. Thereafter, the target was extinguished and participants were manually rotated around the vertical axis. The magnitude of chair rotation was 70°, 80° or 90° depending on the conditions (see Procedure below). The chair was rotated following a bell-shaped velocity profile, which simulates the velocity profiles of natural head movements (Fig. 1b). Peak angular velocities were scaled according to the amplitude of chair rotation, with means of 90°/s (±4°/s), 95°/s (±4°/s) and 101°/s (±4°/s), respectively, and chair rotation lasted approximately 1.5 s.

During the rotation, participants were instructed to press a push-button when they perceived that their body's midline had crossed the target. They were instructed to do the task as accurately as possible. Pressing the push-button produced an analog signal that was recorded synchronously with the angular position of the chair. After the completion of the rotation, participants were brought back to the starting position for the next trial.

Experimental design

Participants took part in four experimental conditions and feedback about spatial accuracy was never provided. In the Pre-test condition ($\mathrm{Pre}^{30}_{\mathrm{CCW}}$), all participants performed one block of five trials. The EFT was presented 30° in the counterclockwise (CCW) direction from participant's body midline and the amplitude of the chair rotation was 80° in the CCW direction. Thereafter, in the Practice condition, the EFT was located 45° in the CCW direction from body midline ($\mathrm{P}^{45}_{\mathrm{CCW}}$ condition). Three different chair rotation magnitudes (i.e., 70°, 80° and 90°) were selected (Mackrous and Simoneau, 2011) to add variability in the point when the target was crossed in order to prevent the learning of internal timing during practice. All rotations were CCW and the magnitudes of rotation were pseudo-randomly selected, with the restriction that every magnitude of rotation was performed equally often within 60 practice trials (12 blocks of five trials). Then, to evaluate whether improvement, if any, generalize to another target eccentricity, the EFT was presented 30° in the CCW direction from participants' midline during the transfer $\mathrm{T}^{30}_{\mathrm{CCW}}$ (i.e., same condition as in the Pre-test). Finally, to assess whether improvement would transfer to the untrained direction, participants performed the task while being rotated clockwise (CW: $\mathrm{T}^{30}_{\mathrm{CW}}$ condition). The target was presented 30° in the CW direction from participants' midline. For both transfer conditions ($\mathrm{T}^{30}_{\mathrm{CCW}}$ and $\mathrm{T}^{30}_{\mathrm{CW}}$), 10 trials were performed and chair rotation amplitudes were 80°. The mean of the first five trials (b1) and the mean of the last five trials (b2) were calculated.

Data analysis

The signed spatial error was calculated from the difference in degrees between the target angular positions and the body midline angular positions when participants responded. CW errors were signed positive while CCW errors were signed negative (Fig. 1c). However, because the same direction of spatial error (e.g., undershooting)