Adaptation of postural symmetry to an altered visual representation of body position

M Lemay[1,2], L-N Veilleux[2], M Marois[2], L Ballaz[1,2], DM Shiller[3]

[1]Département de Kinanthropologie, Université du Québec à Montréal,
C.P. 8888, succursale Centre-Ville, Montréal, Québec, CANADA

[2]Centre de réadaptation Marie Enfant (CHU Sainte-Justine)
5200 Bélanger est, Montréal, Québec, CANADA

[3]École d'orthophonie et d'audiologie, Université de Montréal,
7077 Ave du parc, Montréal, Québec, CANADA

lemay.martin@uqam.ca, lnveilleux@shriners.mcgill.ca, mikael.marois@polymtl.ca, laurent.ballaz@uqam.ca douglas.shiller@umontreal.ca

ABSTRACT

The goal of the present study was to determine whether postural symmetry can be altered through sensorimotor adaptation. A gradual change in postural symmetry was induced in participants by biasing visual feedback of their body's center of pressure toward the left or the right. Results showed that this procedure induced a significant shift in participants' stance, which resulted in postural asymmetry and altered postural control that persisted beyond the period of altered visual feedback. We discuss the implications of such visuo-motor procedures for the rehabilitation of patients with postural asymmetry.

1. INTRODUCTION

Postural control requires continuous processing and integration of feedback from the visual, vestibular and somatosensory systems in order to minimize body sway (Fitzpatrick and McCloskey, 1994). The body center of mass is kept within the base of support through displacements of the center of pressure (COP), which is the point location of the vertical ground reaction force vector. When both feet are on the ground, the net COP tends to lie at a central location between the two feet (Winter, 1995). However, in some patients with unilateral neurological or musculoskeletal deficits, COP deviates from the center of the base of support leading to an asymmetric posture (Shumway-Cook and Woollacott, 2007). These patients maintain more weight on the non-involved leg, which may affect postural control and gait (Ring and Mizrahi, 1991). In these patients, a correction of postural alignment may be required to reduce the risk of falls (Di Fabio and Badke, 1990) and avoid long term musculoskeletal complications such as back pain.

The goal of the present study was to examine the capacity to modify postural alignment in healthy participants using a sensorimotor adaptation paradigm. During sensorimotor adaptation, sensory feedback (e.g., visual or proprioceptive) is manipulated in real-time, and compensatory changes in motor output are examined following a period of practice under such conditions. Numerous studies of sensorimotor adaptation during pointing movements have been carried out in healthy participants, involving visual manipulations (ex. prismatic adaptation) or externally applied force-fields (e.g., Bhushan et al, 2000; Kennedy and Raz, 2005; Martin et al, 2002; Nakajima 1988; Pisella et al, 2006). The results from these studies indicate that the motor system is highly adaptive to changing sensorimotor conditions. However, to our knowledge, this paradigm has never been tested in the context of whole-body postural motor control.

2. METHODS

2.1 Participants, experimental setup and procedures

Twenty healthy participants were tested (20-33 years of age). Participants reported no history of motor or sensory disorder. All participants were asked to stand on a force plate (Advanced Mechanical Tech Inc., Watertown, MA, USA) with their feet parallel to each other (at shoulder width) and arms relaxed at their sides. Markers were affixed to the force plate along each foot to ensure that participants maintained the same position

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throughout the test. The experimental procedure consisted of three phases: 1) the *Adaptation* phase involving postural movement under normal and altered visual feedback conditions, 2) the *No-feedback* condition, involving postural movement with no visual feedback, and 3) the *Wash-out* phase, involving postural control under normal visual feedback conditions. In order to evaluate the changes in postural alignment induced by the Adaptation and Wash-out phases, participants performed one minute of quiet standing (standing still on the force plate while fixating a visual target) at three time points: immediately prior to the Adaptation phase (baseline value), immediately following the Adaptation phase, and immediately following the Washout phase. Postural alignment was determined by computing the foot center of pressure (COP) reflecting, at each moment, the spatial position at which the sum of forces exerted by the body acts on the force plate.

Visual feedback was provided to participants on a 46" screen (2m distance), including a box representing the central "home" position, two target regions (one to the left and one to the right of the home position), and a marker representing the current position of the participant's COP (see Figure 1). Participants were first given a short period of time (approx. 1 min) during which they could move their center of pressure (by shifting their weight) freely in order to familiarize themselves with the on-screen interface. Each trial during the Adaptation and Washout phases then involved maintaining COP in the center position for 3 seconds, moving their COP to the left or the right target, maintaining their position inside the target for 2s, and then moving back to the center base. In the Adaptation phase, participants executed 150 displacements of their COP toward the left or right target (randomized order, 50% of trials in each direction). Changes in the color of the selected target border (from red to green) indicated to which target participants had to move their COP. Following an initial 30 trials under normal feedback conditions, a bias was introduced in the display of the COP to the right for half of the participants and to the left for the other half. The bias was gradually increased over 60 displacements, reaching a maximum of 3 cm. At that point, the COP was located 3 cm to the left or right of the real position of the center of pressure. The full bias of 3 cm was then maintained for 60 displacements.

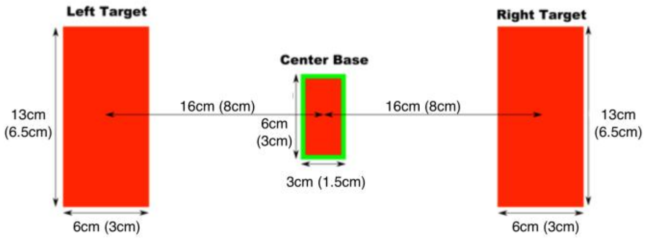

Figure 1. *Positions of the center base and the targets. The distances are presented in units of the on-screen visual representation and the corresponding COP displacement on the force plate (in brackets).*

For the No-feedback phase, the participants were asked to perform 10 COP displacements (5 movements in each direction) replicating the movements performed in the Adaptation phase while the center position, targets and representation of the participant's COP were not visible. Only an arrow indicating to which side participants had to move the COP was visible. This allowed us to determine whether the compensatory changes induced in the Adaptation condition were dependent on the presence of altered visual feedback. The Wash-out phase consisted of 30 trials under conditions identical to that of the Adaptation condition, but with the bias removed (normal visual feedback), at which point the participant unlearned the compensatory changes that took place during the Adaptation phase.

2.2 Data analyses

Force in two dimensions (mediolateral; anteroposterior) was sampled at 50 Hz and digitally low-pass filtered at 6 Hz using a second-order Butterworth filter (Matlab v. 7.0, Mathworks, Natick, MA) prior to the calculation of the COP along each axis (mediolateral and anteroposterior). For the quiet standing trials, COP measures were calculated over the final 50 seconds of the 60 second standing period. In the No-feedback phase, average COP was determined during the first 2s during which participants remained stable in the center area within an area delimited by a 4cm x 4cm square. The difference between the two groups of participants (right bias vs. left bias) was evaluated using independent-samples t-tests. Measures of COP *range* and *mean absolute velocity* along each of the two axes were also calculated during the 1-minute periods of quiet standing to evaluate the impact of the sensorimotor adaptation procedure on postural control. The range and mean velocity of COP have been shown in numerous studies to be reliable indicators of postural performance (Lafond et al, 2004; Raymakers et al, 2005). One-way repeated-measures ANOVAs were carried out separately for each dependent measure (COP range and velocity) and each axis (mediolateral and anteroposterior), comparing Baseline, Adaptation and Washout phases. Post-hoc comparisons were carried out as needed using repeated-measures t-tests with the Holm-Bonferroni correction for multiple comparisons.

3. RESULTS

Immediately following the Adaptation phase, participants in the left-bias group showed an average COP during quiet standing located 0.6 cm to the left of the reference position (Figure 2, left panel), while participants in the right-bias group showed a mean COP of 0.7 cm to the right of the reference position (Figure 2, left panel). This difference between groups in the mediolateral axis was statistically reliable (t(18)=0.0004). Following the Washout period, these biases were reduced to 0.008 cm and 0.2 cm for participants in the left- and right-bias groups respectively, and the difference was no longer statistically significant (p>0.05). No differences between groups were observed in the anteroposterior axis (p>0.05).

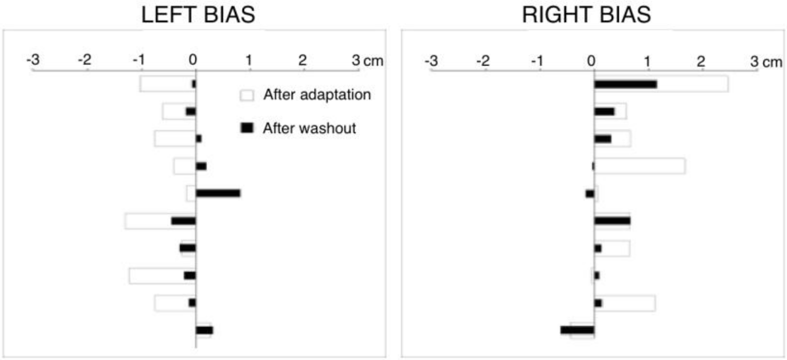

Figure 2. *The mean COP bias observed during 1-minute of quiet standing following the Adaptation and Washout phases for both groups (left and right bias).*

During the period of No-feedback following the Adaptation phase, the mean COP in the mediolateral axis was also found to be significantly different between the two groups (t(18) = 0.0004), corresponding to a 0.8 cm bias to the left of the reference value and 0.5 cm bias to the right for the left- and right-bias groups respectively. This indicates that changes in postural control induced by the altered visual feedback persisted beyond the immediate feedback manipulation. No difference was observed between groups along the anteroposterior axis (p>0.05) during the No-feedback phase.

In addition to the between-group differences in COP presented above, evidence for changes in postural control following the Adaptation phase comes from measures of COP *range* and *velocity* (Figure 3). Across participants in both groups, a reliable overall difference in COP range was observed between phases (baseline, following Adaptation, and following Wash-out) in the mediolateral direction (F[2,46]=9.4, p < 0.001), but not in the anteroposterior direction (p > 0.05). Similarly, a reliable overall difference was found between phases for the measure of COP velocity (F[2,46]=5.8, p < 0.01) in the mediolateral direction, but not in the anteroposterior direction (p > 0.05). Post-hoc tests revealed significantly larger values of COP range following the Adaptation (t[23]=3.99, p<0.01) and Washout phases (t[23]=3.75, p < 0.01) compared to baseline. Similarly, significantly larger values of COP velocity were observed following the Adaptation (t[23]=2.64, p<0.05) and Washout phases (t[23]=2.67, p < 0.05) compared to baseline.

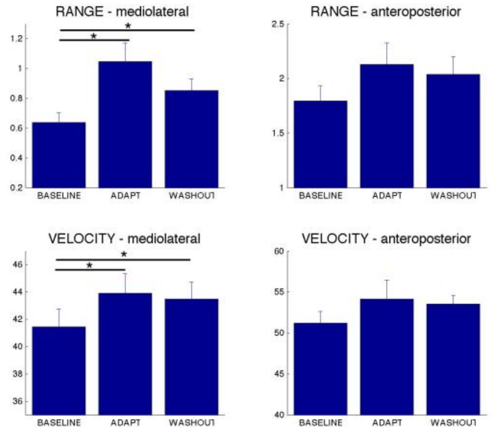

Figure 3. *COP range and velocity in the mediolateral and anteroposterior axes prior to the Adaptation phase (baseline), immediately following the Adaptation phase, and following the Washout phase.(* p< 0.05).*

4. DISCUSSION

The goal of the present study was to examine whether one could induce a short-term postural asymmetry in healthy participants by altering visual feedback during a dynamic postural control task. Following a period of practice under conditions of altered feedback, the COP position during postural quiet standing was found to be reliably shifted in the direction of the visual bias. This shift in COP was found to persist following the Adaptation phase when no visual feedback was present, indicating that the changes in postural motor control had in fact been learned by the participants. The induced postural asymmetry had an impact on postural control, as shown by larger COP range and velocity in the mediolateral axis.

Studies have shown that sensorimotor adaptation is a promising approach for the rehabilitation of upper limb motor control. For example, force-field adaptation during pointing movements has been used to improve the control of upper limb movements in children with primary dystonia (Casallato et al, 2012). Also, prismatic adaptation has been used to alter the attentional field in unilateral visual neglect patients (Jacquin-Courtois et al, 2013; Redding and Wallace, 2006, 2010). To our knowledge, the present study is the first to demonstrate that sensorimotor adaptation can be used to modify postural alignment. Children and adults with hemiplegia often exhibit asymmetric posture that could possibly be corrected using a sensorimotor adaptation procedure. Such clinical applications will be evaluated in future work testing procedures such as those used in the present study in populations with postural deficits.

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