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RESEARCH ARTICLE

Vision can recalibrate the vestibular reafference signal used to re-establish postural equilibrium following a platform perturbation

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Abstract Visuo-vestibular recalibration, in which visual information is used to alter the interpretation of vestibular signals, has been shown to influence both oculomotor control and navigation. Here we investigate whether vision can recalibrate the vestibular feedback used during the re-establishment of equilibrium following a perturbation. The perturbation recovery responses of nine participants were examined following exposure to a period of 11 s of galvanic vestibular stimulation (GVS). During GVS in VISION trials, occlusion spectacles provided 4 s of visual information that enabled participants to correct for the GVS-induced tilt and associate this asymmetric vestibular signal with a visually provided 'upright'. NoVISION trials had no such visual experience. Participants used the visual information to assist in realigning their posture compared to when visual information was not provided ($p < 0.01$). The initial recovery response to a platform perturbation was not impacted by whether vision had been provided during the preceding GVS, as determined by peak centre of mass and pressure deviations ($p = 0.09$). However, after using vision to reinterpret the vestibular signal during GVS, final centre of mass and pressure equilibrium positions were significantly shifted compared to trials in which vision was not available ($p < 0.01$). These findings support previous work identifying a prominent role of vestibular input for re-establishing postural equilibrium following a perturbation. Our work is the first to highlight the capacity for visual feedback to recalibrate the vertical interpretation of vestibular reafference for re-establishing equilibrium following a perturbation. This demonstrates the rapid adaptability of the vestibular reafference signal for postural control.

Keywords Vision · Vestibular · Equilibrium · Perturbation · Sensory integration

Introduction

It is critical to have a sense of body orientation relative to gravitational vertical in order to maintain a balanced upright posture. Sensory feedback from visual, somatosensory and vestibular modalities is integrated to create an appropriate perception of verticality from which to base our actions (Borel et al. 2001; Peterka 2002; Bent et al. 2002). The visual system provides salient cues regarding the body's orientation with respect to visually vertical references. The visual orientation of objects in the environment, the horizon and the direction from which light is coming, for example, are all reliable cues with which to reference our posture (Dobie et al. 2003; Harris 2009). The vestibular system senses the linear acceleration of gravity and provides information about the movement and orientation of the head with respect to gravitational vertical (Hlavacka et al. 1996). The importance of vestibular feedback for postural control is especially evident during dynamic tasks. Previous work has illustrated an increased reliance on vestibular input during dynamic tasks (Bent et al. 2002) and specifically during the re-establishment of equilibrium following a perturbation (Inglis et al. 1995).

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When a permanent vestibular imbalance arises, as in the case of an unilateral vestibular nerve lesion, significant, yet temporary, postural deviations are seen towards the side of the lesion (Borel et al. 2001, 2002). However, over time, the postural control system can utilize alternate sensory feedback to adapt the vestibular imbalance and correct these postural deviations. One mechanism by which the body may adapt to alterations or reductions in sensory feedback is recalibration. Recalibration is the modification or adaptation of a movement or percept that occurs following error feedback (Wilke et al. 2013). Once recalibrated, restoring the previous sensory conditions would require individuals to recalibrate their new behaviour again in order to return the parameters of their movement to previous values (Bastian 2008). Sensorimotor recalibration has been examined following the alteration of one or more sensory feedback sources. For example, recalibration of movement has been shown to occur following the alteration of visual feedback via reversal prism spectacles (Wright 2014).

To study the potential for recalibration of vestibular feedback, we used galvanic vestibular stimulation (GVS) to provide a purely vestibular perturbation. GVS is a technique used to create a temporary and reversible imbalance in the bilateral vestibular afferent signal (Goldberg et al. 1982) by applying a current directly to the peripheral vestibular nerves via the mastoid processes. GVS has been used to demonstrate that, during an active navigation task, the body can rapidly recalibrate its interpretation of a vestibular signal that has been distorted to indicate 'deviation' to instead mean 'straight ahead' by using visual feedback (Sturnieks et al. 2005). While visuo-vestibular recalibration has been shown during navigation, the effect may differ during a postural control task.

In the work by Sturnieks et al. (2005), the visual recalibration of vestibular feedback was achieved specifically during walking with the head bent forward. When the head is oriented this way, GVS does not perturb the body's postural equilibrium (Cathers et al. 2005), but rather influences the use of vestibular information for steering during navigation. When the head is upright, GVS has been shown to alter one's ability to achieve postural equilibrium following a balance response triggered by a platform perturbation (Inglis et al. 1995). The different use of vestibular information between navigation and this postural recovery task led us to question whether vision can also be used to recalibrate the body's vestibular interpretation of vertical to influence the establishment of postural equilibrium following a perturbation.

The purpose of the current study was to determine whether the vestibular interpretation of vertical could be recalibrated to a visual interpretation of vertical, during a postural recovery task. Postural responses to platform perturbations preceded by GVS were compared between conditions in which an intermittent period of visual feedback was or was not provided. We hypothesized that introducing orientation-rich visual feedback during GVS prior to a platform perturbation would alter the influence of vestibular reafference on final equilibrium positions following the platform perturbation. Any such alteration would indicate that visual feedback can indeed be used to recalibrate the body's interpretation of vestibular 'vertical'.

Methods

Participant characteristics

Seven male and two female participants (age 23 ± 0.9 years; height 1.77 ± 0.02 m; mass 73.0 ± 2.5 kg; mean ± SE) with no history of neuromuscular or neuro-otological disorders participated in the study. Individuals provided written informed consent prior to participating in the study. The experimental protocol was approved by the University of Guelph Research Ethics Board and conforms to the standards set by the Declaration of Helsinki.

Equipment and setup

Participants stood (inter-metatarsal distance 4 cm) on a force plate (model 9281B, Kistler Instrumente AG, Winterthur, Switzerland), which lay flush with the surface of a hexapod motion platform (Mikrolar Inc, NH, USA). Forces and moments were recorded (100 Hz) using a custom LabVIEW program. Participants wore a safety harness with enough slack to allow movement about the platform while preventing falls (no falls were recorded). Participants wore fitted clothing and six passive makers were placed on anatomical locations: the left and right temporo-mandibular joints (TMJs), left and right acromia, and left and right anterior–superior iliac spines (ASISs). One additional marker was placed on the motion platform. Kinematic data were collected at 100 Hz using a 12-camera Optitrack motion capture system (Natural Point Inc, Oregon, USA). To control the timing of visual availability throughout the protocol, participants wore PLATO™ LCD spectacles (Translucent Technologies, Toronto, Canada) that contained lenses that could be made opaque during data collection.

To alter vestibular feedback, bipolar binaural GVS (Linear Isolated Stimulator A395, World Precision Instruments Inc, FL, USA) was applied via two Ag/AgCl electrodes placed bilaterally on the skin overlying each mastoid process. The GVS was delivered as a square pulse at a current 2× each participant's individual threshold (determined as the smallest amount of current required to elicit a noticeable postural response; range 0.30–0.75 mA; Bent et al. 2000). The duration of the GVS was 11 s, the timing of which is indicated in Fig. 1.

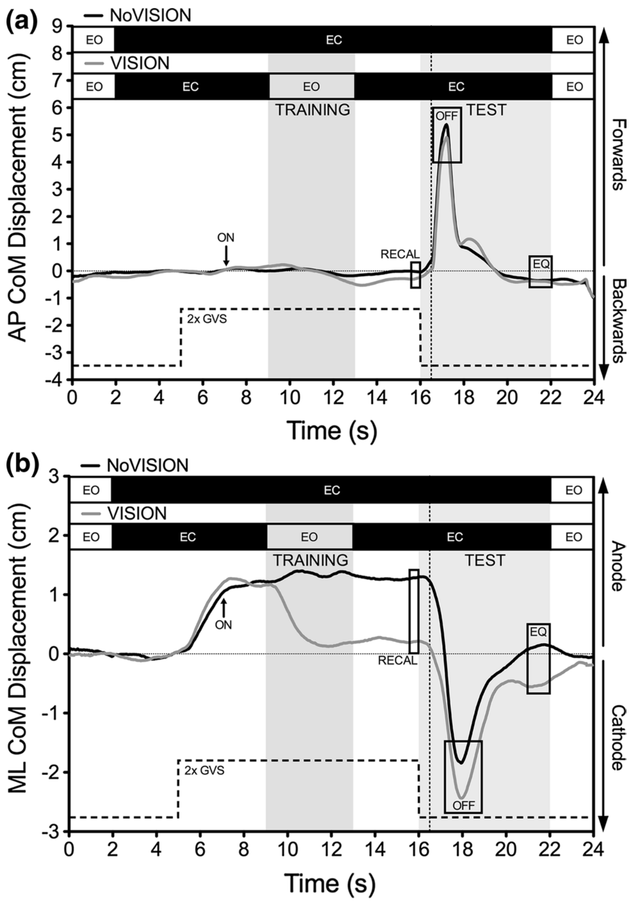

Fig. 1 **a** Ensemble average of the AP CoM displacement versus time for NoVISION (*black trace*) and VISION (*grey trace*) conditions. **b** Ensemble average of the ML CoM displacement versus time for NoVISION (*black trace*) and VISION (*grey trace*) conditions. EO and EC denote periods of visual availability and visual occlusion, respectively. The waveform (including timing and magnitude) of the GVS used for both conditions is shown by the *dashed trace*. The *dotted vertical line* indicates the onset of the forward perturbation for both conditions. Training and test phases of the protocol are indicated by the regions of light *shading*, and areas from which ON, RECAL, OFF and EQ variables were calculated are indicated in both **a** and **b**

To evoke postural perturbations, support-surface perturbations were applied, which consisted of a 9 cm backward platform translation (thus perturbing the participant forward) with a trapezoidal velocity profile (peak 14 cm/s) and peak acceleration of 1.8 m/s^2. Catch trials with left, right, forward and no platform perturbations (not included in the analyses) were also performed in an attempt to keep testing conditions unpredictable. Posterior platform perturbations were coupled with medio-lateral GVS postural responses to allow for a clear distinction of the separate effects of the GVS and mechanical platform perturbations (See Supplementary Fig. 1 for AP and ML responses to the posterior platform perturbation in the absence of GVS). Previous work has indicated that when coupling the direction of the GVS and platform perturbation directions, it is difficult to dissociate vestibular versus mechanical influences on early recovery responses when using force plate measures (Horak and Hlavacka 2002).

Protocol

Participants were instructed to stand relaxed and to maintain their balance as best they could without altering their foot placement. They were also instructed to 'use vision, when available, to realign any deviations in your vertical posture'. When vision was made available, participants reported using many vertical and horizontal cues along the wall in front of them, including the door into the laboratory, the concrete blocks that make up the wall and the camera pole in front of them.

Each trial began with 2 s of quiet standing prior to visual occlusion. Three seconds after the removal of vision, participants received 11 s of GVS. Four seconds after GVS onset, participants either had vision restored for 4 s (VISION condition) (referred to as the 'RECALIBRATION' period in Fig. 1) or remained standing in the absence of vision (NoVISION condition). Five hundred milliseconds following the removal of GVS, a platform perturbation was applied in the posterior direction and data collection continued (in the absence of vision) for 6 s (referred to as the 'TEST' period in Fig. 1), after which vision was restored in both conditions. Figure 1 illustrates the timings of GVS, platform motion and visual availability in both NoVISION and VISION conditions. A control condition in the absence of GVS was also collected. During this condition, a platform perturbation occurred in the absence of vision 5.5 s after the start of the trial. Each participant was exposed to trials in five blocks. Each block contained two trials each of the VISION and NoVISION conditions (anode-left and anode-right) with a forward perturbation, a control trial and one of the three catch trials (left, right and backward perturbations) in a randomized order.

Data analysis

All data processing was performed using Visual 3D software (C-motion Inc, MD, USA). Kinematic data were interpolated over a maximum gap of three frames (30 ms) using a second-order polynomial. Both kinetic and kinematic data were filtered using a second-order dual low-pass Butterworth filter with a cut-off of 5 Hz. In order to remove platform motion artefacts from anatomical marker trajectories in each trial, the platform marker data were subtracted from the marker data at each anatomical location. After validation against a 21-marker whole-body centre of mass (CoM) model (Winter et al. 1998), Visual 3D head (TMJ and acromion markers) and trunk (acromion and ASIS markers) segments were created and used to develop a reduced whole-body CoM model. Centre of pressure (CoP) displacements were calculated from the force and moment data collected from the force platform. CoM and CoP traces for each trial were zeroed to the average displacement within a 500-ms window of quiet stance immediately prior to GVS onset. Both CoM and CoP traces for each condition were then averaged across trials to create anode-left and anode-right traces for each participant in both antero-posterior (AP) and medio-lateral (ML) planes.

To quantify postural behaviour during each condition, four dependent variables were calculated from each of the ML and AP CoM and CoP traces: ON response, RECAL position, OFF response and EQ position (see Fig. 1). For ML traces, the postural response to GVS initiation (ON response) was quantified as the average displacement within a 50-ms window 2 s after GVS onset. A small 50-ms window was chosen to represent the peak response while mitigating the influence of unusual postural shifts during the response. Bipolar GVS has previously been shown to have little to no effect on AP postural sway when the head is facing forward (Lund and Broberg 1983; Séverac Cauquil et al. 2000). Therefore, in order to encapsulate participants' AP posture during GVS onset, the ON response was determined by measuring the average displacement within a 1-s window, 2 s after stimulus onset. The RECAL position, which describes the ML and AP position of each participant's CoM and CoP immediately prior to removing the GVS stimulus, was determined by calculating the average displacement over a 500-ms window immediately prior to GVS termination. The OFF response, resulting from the paired removal of GVS with the onset of the platform perturbation, was calculated as the peak displacement relative to vertical in the 3-s window following the GVS offset for both ML and AP CoM and CoP traces. The magnitude of the OFF response relative to the RECAL position (OFF–RECAL) was also calculated to capture the full movement of the body in response to the paired vestibular and mechanical perturbations. The final equilibrium position adopted by participants after their initial perturbation response (EQ) was calculated as the average displacement over a 1-s window at the time point 5 s after GVS termination for both AP and ML data. The average displacement over 1 s has been used to represent postural equilibrium following a platform perturbation in previous work (Hlavacka et al. 1999).

Statistics

Statistical analyses were carried out using SAS (version 9.3) statistical software. A Shapiro–Wilk analysis was used to test the normality of data residuals, and a compound symmetry covariance structure was used within a mixed model to avoid violations of sphericity. A mixed-model two-way (Anode × Vision) repeated-measures ANOVA was performed on each variable (ON, RECAL, OFF, OFF–RECAL and EQ for AP and ML CoM and AP and ML CoP). Upon demonstrating no effects due to the side of stimulation (Anode), left and right data were pooled and differences between VISION and NoVISION conditions were analysed using paired t tests. In order to test for differences between an ON and RECAL response within a single condition, a priori t tests were conducted to compare ML ON responses against ML RECAL positions within each of the VISION and NoVISION conditions. A one-way repeated-measures ANOVA was performed to specifically compare EQ positions between VISION, NoVISION and Control conditions to further confirm whether vision influenced the re-establishment of postural equilibrium following a platform perturbation. All data are presented as mean ± standard error and significance was set at $p < 0.05$.

Results

Antero-posterior centre of mass and centre of pressure responses

CoM (Fig. 1a) and CoP (data not shown) positions were not observed to deviate in response to GVS over the entirety of each visual condition. AP displacements did not differ between VISION and NoVISION conditions for ON responses (CoM $p = 0.87$ (Fig. 2a); CoP $p = 0.90$) or RECAL positions (CoM $p = 0.13$ (Fig. 2a); CoP $p = 0.31$). In response to the paired GVS offset and forward perturbation (OFF response), participants exhibited large anterior CoM (Fig. 1a) and CoP postural responses. However, there were no significant differences in AP OFF response magnitude between VISION and NoVISION conditions (CoM $p = 0.22$ (Fig. 2b); CoP $p = 0.43$). After exhibiting large initial postural responses, participants adopted quiet standing EQ positions that also did not differ between VISION and NoVISION conditions (CoM $p = 0.87$ (Fig. 2c); CoP $p = 0.86$). Overall, no significant differences were found between NoVISION and VISION conditions for any of the AP variables.

Medio-lateral centre of mass and centre of pressure responses

Following GVS onset, participants demonstrated CoM (Fig. 1b) and CoP (Supplementary Fig. 2) postural deviations towards the anode electrode (CoM 1.0 ± 0.1 cm (Fig. 1b); CoP 1.5 ± 0.1 cm). No significant differences were found in the ON response (2 s after GVS onset and 2 s before vision might become available) between the

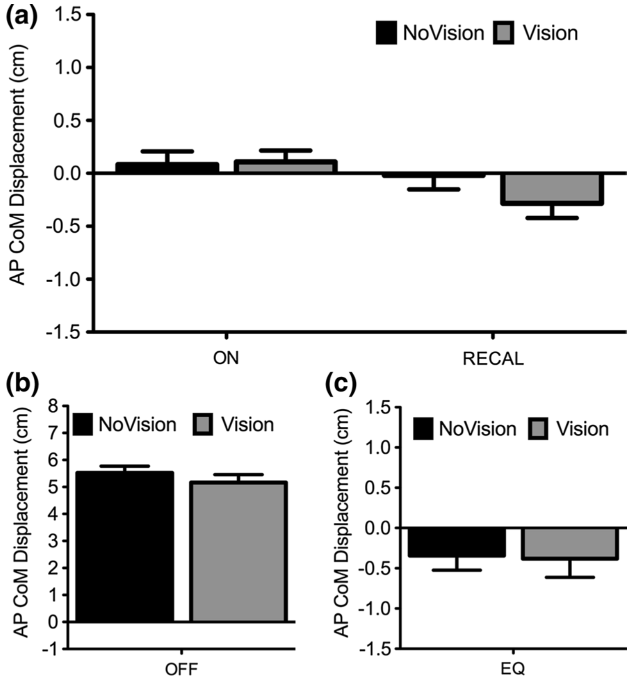

Fig. 2 **a** AP ON and RECAL CoM positions (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*grey bars*) conditions. **b** AP OFF CoM responses (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*grey bars*) conditions. **c** AP EQ CoM positions (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*white bars*) conditions

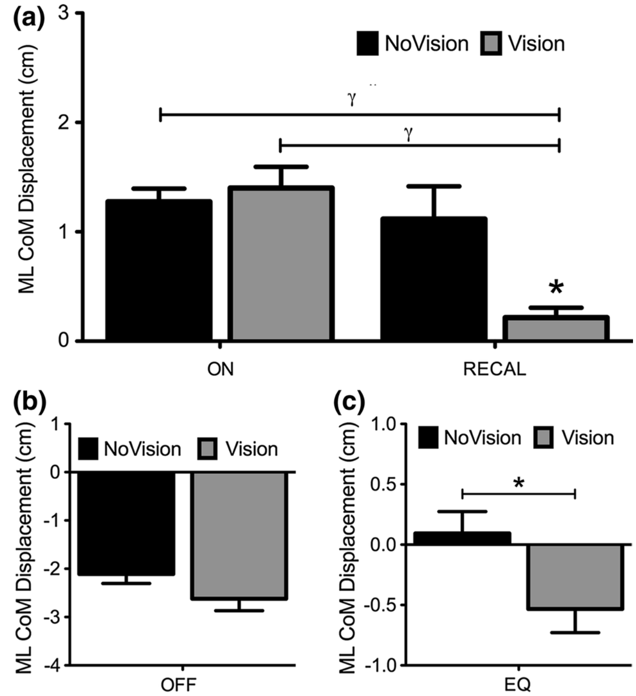

Fig. 3 **a** ML ON and RECAL CoM positions (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*grey bars*) conditions. *Asterisks* denote a significant difference between NoVISION and VISION RECAL positions, and γ denotes a significant difference between ON and RECAL positions. **b** ML OFF CoM responses (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*grey bars*) conditions. **c** ML EQ CoM positions (mean ± 1 SE) calculated for NoVISION (*black bars*) and VISION (*white bars*) conditions. *Asterisks* denote a significant difference between NoVISION and VISION conditions

VISION and NoVISION conditions (ML CoM $p = 0.22$ (Fig. 3a); ML CoP $p = 0.21$).

During the RECAL period (just prior to GVS offset, labelled RECAL in Fig. 1b) in the NoVISION condition, participants remained affected by the GVS, demonstrated by no significant difference in their deviation from their ON response (CoM $p = 0.58$ (Fig. 3a); CoP $p = 0.24$). In contrast, there was a significant difference between the RECAL and ON positions in the VISION condition (CoM $p < 0.01$ Fig. 3a); CoP $p < 0.01$), indicating that participants were able to successfully realign their vertical posture during the VISION condition. RECAL positions were also found to significantly differ between VISION and NoVISION conditions (CoM $p < 0.01$ (Fig. 3a); CoP $p < 0.01$).

In response to GVS offset and the forward perturbation in both visual conditions (NoVISION, VISION), participants demonstrated ML OFF responses which were larger in absolute magnitude ($p < 0.01$; not shown) and opposite in direction (i.e. towards the cathode) relative to their ON responses (Fig. 1b). No significant difference was found between OFF responses in the VISION compared to the NoVISION condition (CoM $p = 0.09$ (Fig. 3b); CoP $p = 0.17$). Moreover, the magnitudes of the OFF responses relative to the RECAL positions (OFF–RECAL) were no different between the two conditions (CoM; NoVISION −3.2 ± 0.3 cm and VISION −2.8 ± 0.2 cm) (CoM $p = 0.24$; CoP $p = 0.58$). Overall, the initial postural response following the paired removal of GVS and platform perturbation did not significantly differ based on prior visual availability.

The final equilibrium position (labelled EQ in Fig. 1b), adopted by participants after the perturbation, was significantly deviated towards the cathode in the VISION compared to the NoVISION condition (CoM $p < 0.01$ (Fig. 3c); CoP $p < 0.01$). A one-way repeated-measures ANOVA revealed a main effect between NoVISION, VISION and Control (NoGVS) conditions (CoM $F_{(2,16)} = 4.48$, $p = 0.03$; CoP $F_{(2,16)} = 8.07$, $p < 0.01$). Post hoc comparisons revealed that EQ positions differed between VISION and Control (CoM $p = 0.04$; CoP $p < 0.01$), but not between NoVISION and Control conditions (CoM $p = 0.55$ (Fig. 3c); CoP $p = 0.61$). Specifically, EQ positions were deviated in the direction of the cathode in the VISION condition, whereas no deviation of EQ positions was observed in the NoVISION and Control conditions. Values for RECAL, OFF and EQ CoM and CoP variables

Table 1 ML CoM and CoP RECAL positions, OFF responses and EQ positions during VISION and NoVISION conditions. Positive and negative values represent movement towards the anode and cathode respectively

ML	Mean ± SE		
	RECAL	OFF	EQ
CoM			
NOVISION	1.1 ± 0.3	−2.1 ± 0.2	0.1 ± 0.2
VISION	0.2 ± 0.1	−2.6 ± 0.3	−0.5 ± 0.2
CoP			
NOVISION	1.5 ± 0.4	−4.4 ± 0.3	0.2 ± 0.2
VISION	0.4 ± 0.1	−5.1 ± 0.4	−0.6 ± 0.2

Values are expressed as mean ± SE and units are in cm

in both VISION and NoVISION conditions can be found in Table 1.

Discussion

The current work examined whether visual feedback during GVS could alter the interpretation of perceived vestibular vertical during perturbation recovery. Our results support our hypothesis that participants were able to use visual feedback during GVS to realign their posture and overcome the effect of GVS. Additionally, the resultant new interpretation of vestibular vertical (recalibration) altered the final equilibrium position (EQ) when GVS was removed, evidenced by responses that were significantly shifted from those in trials with no visual feedback provided during GVS.

Vestibular response

Bipolar binaural GVS is known to create an illusion of head movement towards the cathode electrode which, when the head is facing forward in the absence of vision, is corrected for by a whole-body medio-lateral (ML) postural deviation towards the anode (Fitzpatrick and Day 2004). The final tilted posture adopted in the presence of GVS is suggested to result from an attempt to realign the body with an altered internal representation of vertical (Inglis et al. 1995; Hlavacka et al. 1999). In the current study, all participants demonstrated ML postural sway in response to GVS, and ON responses were consistent between the NoVISION and VISION conditions. Previous studies using similar GVS current magnitudes have reported ML head deviations of approximately 1.5 cm (Osler et al. 2013) and CoP displacements of approximately 2 cm (Day and Guerraz 2007). Sway magnitudes in our study were found to be similar to those previously reported (mean 1.3 cm of head deviation and 1.6 cm of CoP displacement).

Visual recalibration?

Previous work has demonstrated that during perturbation recovery, vestibular reafferent information is utilized to establish the body's final equilibrium position, within approximately 6 s after perturbation onset (Inglis et al. 1995). During the NoVISION condition, GVS resulted in participants adopting a shifted equilibrium posture towards the anode that was successfully restored following the initial OFF response (EQ data, average body position between 5 and 6 s following GVS removal). These data show that participants were successful at using their baseline vestibular feedback (no longer influenced by GVS) to re-establish their vertical equilibrium. However, when vision was provided during GVS in the VISION condition, participants used visual feedback to vertically realign their posture in the continued presence of the galvanic vestibular stimulus. When GVS was then removed in the VISION condition, participants adopted a new equilibrium position that was deviated away from vertical in the other direction, towards the cathode. This equilibrium position represents the average steady state of the body, between 5 and 6 s following the removal of GVS. As a result, any impact of short-term oscillations on the EQ position is negated by taking the average value during this window, as it acts as a low-pass filter. Together, these data suggest that during the visually aided realignment of posture in the presence of GVS, participants are likely recalibrating their perturbed vestibular afferent feedback to signal a vertical orientation. Therefore, upon the termination of the vestibular stimulus, baseline vestibular afferent feedback no longer represented a vertical equilibrium position, but instead indicated a deviation such that participants adopted an equilibrium posture deviated towards the cathode.

Although subjects were able to realign their posture using the available visual feedback, we cannot be certain that vision was the only sensory modality aiding this postural realignment. Previous work has shown that the presence of either visual (Smetanin et al. 1990; Day and Guerraz 2007) or somatosensory feedback (Maaswinkel et al. 2013) can be used to reduce GVS postural responses. Therefore, it is possible that subjects may be using the available visual feedback as a cue to enhance somatosensory feedback for the realignment of their posture (Press et al. 2004; Longo et al. 2008). We are confident, however, that vision is significantly contributing to the postural realignment observed in the current study for two reasons. First, participants were specifically instructed to use vision and reported using specific vertical or horizontal visual cues to aid their postural corrections. Additionally, when a period of visual feedback was not provided, participants remained affected by the GVS since the RECAL CoM and CoP positions did not differ from the GVS ON positions for the NoVISION trials (Fig. 3a).

Recalibration of initial perturbation responses

Although equilibrium positions were altered by visual recalibration, no significant difference was found in the ML component of initial recovery responses to the platform perturbation; there was no difference between the VISION and NoVISION conditions when examining either the ML OFF or OFF–RECAL responses. Previous work has suggested that vestibular information has minimal influence on the initial component of perturbation recovery (Inglis et al. 1995; Hlavacka et al. 1999). Inglis et al. (1995) showed no vestibular influence on the initial CoP trajectories in response to an AP perturbation, but found a significant vestibular contribution, based on GVS polarity, to the final equilibrium position adopted by participants. Additionally, Peterka and Benolken (1995) demonstrated that vestibular signals contribute to CoM stabilization at lower velocities even when competing somatosensory information was reliable. This supports the lesser role of vestibular feedback during initial high-velocity perturbation responses and the greater role during the slower re-establishment of equilibrium. Therefore, it may be that the current study design cannot exploit the potential for vision to alter the vertical interpretation of vestibular feedback during a perturbation recovery response simply because vestibular feedback is only preferentially used to re-establish equilibrium *following* the initial recovery response.

Importantly, previous work that has highlighted a minimal influence of vestibular feedback on initial perturbation responses has defined these 'initial vestibular contributions' as occurring within the first 500 ms following perturbation onset (Hlavacka et al. 1999). However, initial perturbation responses in the current study were calculated over a timeframe of 2–3 s following GVS offset. Therefore, it may not be reasonable to directly compare the initial responses from these different studies. Instead, we believe the latency (3-s window) of the 'initial' response in the current study allowed for a greater vestibular contribution (as evidenced by a ML OFF response whose absolute magnitude was larger than the ON response). Despite the potential for a greater vestibular effect, vision showed no ability to recalibrate the influence of vestibular feedback on the 'initial' response, as no difference for either the OFF or OFF–RECAL responses was observed between NoVISION and VISION conditions.

Sturnieks et al. (2005) demonstrated that, during gait, vision could be used to recalibrate the interpretation of GVS-biased vestibular feedback to signal straight ahead. However, the visuo-vestibular recalibration was only successful when participants actively walked and not when they were passively moved along the path in a wheelchair. Moreover, previous work on sensory recalibration has indicated that in order to adapt how sensory input is used during a task, sensory recalibration must occur via the accumulation of sensory feedback during the completion of that same task (Wilke et al. 2013; Wright et al. 2014). The visual feedback made available to participants in the current study provides a static orientation reference about body tilt, and postural realignment only occurred during the task of quiet standing. Therefore, it is possible that the feedback provided by vision during a quiet standing task is not sufficient to recalibrate the vestibular signal used during the initial response to a platform perturbation. If vision were provided in the presence of GVS *during*, rather than before, the mechanical perturbation, a recalibration effect on initial recovery responses may be revealed.

Conclusion

This study has demonstrated for the first time that visual information can be used to recalibrate the vertical interpretation of vestibular feedback used during the re-establishment of equilibrium following a platform perturbation. Specifically, we showed that prior visual feedback is used to reinterpret the vestibular signal for 'vertical' during a later recovery of equilibrium. This rapid adaptability has implications for situations where the quality of visual feedback may be altered or reduced, as these changes may affect visuo-vestibular sensory integration, leading to altered vestibular postural responses.

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