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Original Article

Postural Control Adjustments with Sensory Manipulations and External Perturbations in Older Adults: Electromyographic Analysis of Lower-limb & Trunk Muscles

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Abstract

Objectives: To examine the influence of vision and somatosensory information on anticipatory postural adjustments (APA) and compensatory postural adjustments (CPA) in response to an external perturbation in older adults. **Methods**: Twenty healthy older adults were included in the study. Postural stability was tested under four different vision and surface support conditions using a sandbag drop while the participants were holding a tray. Electromyography (EMG) latency, amplitude amplitude - root mean square (RMS) of the erector spinae (ES) and lateral gastrocnemius (LG) muscles and centre of pressure (COP) displacement were recorded. **Results**: Significant differences in muscle activity and COP displacements were observed across visual and somatosensory conditions. LG activity and compensatory COP displacement (CPA-COP) were significantly greater under eyes-closed and unstable surface conditions (ECUS). This indicates that the absence of visual input and altered somatosensory feedback independently and collectively amplify compensatory postural responses. Anticipatory responses were less effective under sensory- compromised conditions. **Conclusions**: Both vision and somatosensory inputs critically influence APA and CPA in older adults. Visual deprivation and unstable surfaces reduce the efficiency of APA and heighten CPA, reflecting the need to address both systems in balance training.

Keywords: Anticipatory Postural Control, Compensatory Postural Control, Postural Control, Somatosensory Feedback, Visual Feedback

Introduction

Body position changes occur frequently and often unpredictably during daily life activities. However, in older adults, delayed response to these disturbances can alter the body's stability and balance, which may lead to a likelihood of falling[1]. The complex phenomenon of postural control helps in controlling the centre of gravity (COG) of the human body within the base of support in a given environment[2]. The central nervous system perceives and anticipates disruptive events and reacts to produce the appropriate muscle contractions to counterbalance any postural disruptions[3]. The two central nervous system-controlled mechanisms involved in postural control mechanisms are anticipatory postural adjustments (APA)[4,5] and compensatory postural adjustments (CPA)[6,7]. APA are feed-forward control which are top-down in nature, while CPA are feedback control which are a bottom-up reflex generated by the lower centres of the nervous system[3]. APA decrease the body's centre of mass (COM) displacement before a perturbation occurs[4] while the CPA recovers the function of COM after a disturbance has already occurred[8]. Prior studies have indicated that

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older adults may experience compromised APA due to the diminished physiological function of the various systems associated with aging. The decline in the physiological processes in this population leads to a higher susceptibility to falls[9–12].

The external and internal perturbations acting on the human body can be a challenge to static as well as dynamic postural control. External perturbations arise from external forces such as push, pull, or gravitational forces acting on the body. In contrast, internal perturbations may originate due to self-initiated movements such as lifting an arm, shifting weight, or initiating a step, which can alter body's centre of mass and disturbs postural stability[13]. The APA[14] and CPA[6] help in maintaining the equilibrium of the body when perturbations challenge its stability. During these postural adjustments, the activation of muscles of the lower extremities, trunk, and inputs from visual, somatosensory and vestibular inputs are essential[15–17]. However, deprivation or impairments in sensory or motor components may cause alterations in APA and CPA to restore balance and equilibrium when it is disturbed by either an internal or external perturbation. These studies have investigated the postural stability on either internal perturbations[18,19] or external perturbations[20].

Though the role of vision and somatosensory inputs has been investigated in younger adults[21], there is a dearth of information in this regard in older adults. The postural control components undergo age-related decrements which may lead to changes in postural adjustments[22]. These changes include increased muscle co-activation, reducing the flexibility of postural responses and leading to a rigid postural strategy[23]; reorganization of cortical and spinal control mechanisms, characterized by increased cortical activation and disinhibition[24]; and difficulty in performing dual-task activities, often prioritizing postural stability over cognitive performance, resulting in poorer postural outcomes[25]. Additionally, aging further impairs sensorimotor integration, as demonstrated by increased body sway and distinct neural activation patterns during balance activities[26]. These deficits become more pronounced in dynamic activities, such as walking or while responding to external perturbations, where older adults often exhibit delayed and inconsistent postural responses[27,28].

Most of the studies where an external loading is used to investigate the effect of external perturbations are applied around the trunk region[29–31]. There is a scarcity of research examining the application of an external load on the upper extremity, such as catching a load. This scenario resembles a real-life event in which Individuals may intercept objects hurled towards them. This study investigated the effect of visual information availability and somatosensory inputs on the relationship between the APA and CPA. We hypothesized that postural responses would be influenced by the availability of visual and somatosensory inputs with external perturbations, resulting in differences in anticipatory and compensatory adjustments, as reflected in electromyographic (EMG) activity and centre of pressure (COP) displacement. These results could be beneficial for designing exercise programs for elderly individuals, particularly if there are alterations in the postural control system under the specific settings examined in the study.

Materials and Methods

Participants

Twenty healthy older adults, aged above 60 years, with normal or corrected to normal hearing and vision were recruited in the study. Participants were excluded if they had any mental health disorders, any orthopaedic condition that limited their mobility, impaired cognition, inability to follow commands, presence of metabolic disorders, or a history of disorders affecting balance.

Sample size

A sample of 20 subjects was determined with G*power 3.1.9.2 using data from a study conducted by Claudino et al with an effect size of 1.0, power of 0.90, and α of 0.05[32].

Procedure

Ethical approval was obtained for the study from the institutional ethics committee (IEC), Jamia Millia Islamia, New Delhi, India. The study was conducted in accordance with the ethical principles outlined in the declaration of Helsinki. Twenty healthy older adults participated in this study. The participants were recruited from the local community near to the institution where the study was conducted. The participants were informed about the study through the distribution of leaflets. Prior to the commencement of the trial, all the participants provided their written informed consent. Following the initial screening process to determine eligibility, the participants' overall demographic information and clinical data were documented.

The participants were tested for postural control under four experimental conditions: (1) eyes open stable surface (EOSS), (2) eyes open unstable surface (EOUS), (3) eyes closed stable surface (ECSS), and (4) eyes closed unstable surface (ECUS). Before the start of the actual testing, the subjects had two practice session trials to familiarize themselves with the tasks. The sequence of the four trial conditions was random for each participant. For each of the four experimental conditions, three successful trials were recorded for analysis. Trials with excessive movement artifacts, loss of balance, or technical recording errors were discarded and repeated to ensure three valid trials per condition. Adequate rest was given between trials to minimize fatigue. During the sandbag-hitting test, the participants were instructed to stand barefoot with their feet shoulder-width apart. External perturbation was applied to the upper body by manually dropping a sandbag of 2 kg into a plastic tray, which was held by the subject with both hands. The upper arm was vertical to the ground and the elbow was flexed at 90°.

The examiner stood in front of the participant holding a sandbag on their hands. The release height was standardized relative to the tray, with the bottom of the sandbag positioned approximately 30 cm above the tray surface (corresponding to eye level), ensuring comparable perturbation impulse across participants. The examiner then released the hold of the sandbag, so that it dropped into the centre of the plastic tray. The tray mass was approximately 0.9 kg, also kept constant for all participants across all trials and experimental conditions. Participants were instructed to maintain the stability of their bodies and arms throughout the procedure. This procedure was performed under the four above-mentioned conditions (EOSS, EOUS, ECSS, and ECUS). For testing on the stable surface, the participants stood on the floor, while for the unstable surface, the participants stood on a foam cushion with a size of 18″ × 18″ × 3.5″.

The onset of perturbation (TO) was defined as the moment at which the externally applied load initiated a mechanical disturbance to the participant. In accordance with Zhang et al. (2019), TO was identified from the perturbation signal as the first detectable rise recorded by the vibration/acceleration sensor attached to the apparatus. This signal provided an objective temporal reference independent of neuromuscular or postural responses, and all EMG and COP signals were time-aligned to TO[33].

Assessment of muscle activity

Electrode placement for the recording of electromyography (EMG) was in accordance with recommendations reported in surface electromyography for non-invasive assessment of muscles (SENIAM) guidelines[34]. The electrical activities of the erector spinae (ES) and lateral gastrocnemius (LG) muscles were recorded. These specific muscles were selected because of their involvement in the control of vertical posture while dealing with symmetrical perturbations, and they have been previously studied to assess anticipatory and compensatory control of posture[35]. After the skin was cleaned with alcohol swabs, disposable bipolar Ag/AgCl surface electrodes were placed over the belly of the aforementioned muscles. Electrode placement for ES: One electrode was placed 3cm lateral to the L4 spinous process, whereas the second electrode was placed 2cm directly below the first electrode[33]. Electrode placement for LG: Both electrodes were placed 1/3 of the line between the head of the fibula and the heel. A reference electrode was placed on the lateral malleolus.

Lab Chart software, version 7, AD instruments, New Zealand was used to record the EMG activities. All raw EMG signals were bandpass filtered between 20-500 Hz and sampled at 1000 Hz. To identify baseline activity,the mean and standard deviation (SD) of the EMG signal were calculated from -500 to -350ms relative to TO.

Muscle onset latency (activation or inhibition) was detected within a window spanning -250 to +250ms relative to TO using an automated threshold-based algorithm and subsequently confirmed by visual inspection of ensemble-averaged EMG traces to minimize false detections due to noise. The latency of a specific muscle was defined as the instant lasting for at least 15ms when its EMG amplitude was greater (activation) or smaller (inhibition) than the mean ± 2 SD of the baseline. Pooled analysis of activation and inhibition latency values was done, and no separate subgroup analysis was performed.

For amplitude analysis, EMG signals were full-wave rectified, and root mean square (RMS) values were calculated over the predefined APA and CPA time windows. RMS values were calculated separately for each valid trial within the predefined APA and CPA time windows. For each participant, RMS values were then averaged across the three trials within each condition to obtain a representative value for statistical analysis. EMG amplitudes were not normalized to maximal voluntary contraction; therefore, RMS comparisons were restricted to within-subject and within-session conditions.

For phased analyses, APA were analysed within a time-window from -250 to +50ms relative to the onset of perturbation (TO), consistent with previously published sudden loading paradigms. This interval represents an anticipatory-dominant phase that includes both pre-perturbation muscle activity and very early post-perturbation responses temporarily linked to predictive motor control. CPA were analysed within the time window from +50 to +250ms relative to TO, reflecting later feedback- driven responses. This temporal segmentation follows established control literature[3,4,33,36].

Measurement of COP Displacement

COP displacement was measured using the Pedalo®-Sensomove balance system (Sensbalance Mini Board, Utrecht, the Netherlands) which consists of a mini-board and hemispherical-shaped sensors that are placed below the mini-board. After positioning the board, the device was calibrated. COP displacement was analyzed along the antero-posterior axis. Based on the laboratory coordinate system, forward COP displacement was represented by negative values, whereas backward displacement was represented by positive values.

For COP analysis, COP displacement was quantified separately for the APA and CPA phases using the same temporal segmentation as EMG. The anticipatory COP (APA-COP) phase (-250 to +50ms) reflects anticipatory-dominant adjustments, whereas the compensatory COP (CPA-COP) phase (+50 to +250ms) reflects compensatory postural control. COP at TO was defined as the instantaneous centre of pressure position at the exact moment of perturbation onset. This value was extracted

Table 1. Descriptive characteristics of variables (Mean ± S.D; N=20).

Variables	Mean	Standard Deviation
Age (yrs)	64.25	4.58
Height (m)	1.63	0.08
Weight (kg)	61.70	5.60
BMI (kg/m^2)	23.63	1.77
Latency		
APA LG EOSS (ms)	-42.05	50.32
APA LG ECSS (ms)	-58.80	76.15
APA LG EOUS (ms)	-16.15	77.40
APA LG ECUS (ms)	-69.30	73.03
APA ES EOSS (ms)	-65.70	72.32
APA ES ECSS (ms)	-62.55	79.93
APA ES EOUS (ms)	-23.65	57.59
APA ES ECUS (ms)	-76.25	62.94
CPA LG EOSS (ms)	147.45	40.65
CPA LG ECSS (ms)	136.60	53.17
CPA LG EOUS (ms)	143.60	49.28
CPA LG ECUS (ms)	153.45	40.81
CPA ES EOSS (ms)	128.10	35.66
CPA ES ECSS (ms)	145.35	43.97
CPA ES EOUS (ms)	107.85	38.09
CPA ES ECUS (ms)	150.70	47.89
Root mean square		
APA LG EOSS	0.02	0.02
APA LG ECSS	0.01	0.01
APA LG EOUS	0.04	0.07
APA LG ECUS	0.02	0.01
APA ES EOSS	0.02	0.02
APA ES ECSS	0.01	0.01
APA ES EOUS	0.02	0.01
APA ES ECUS	0.01	0.01
CPA LG EOSS	0.01	0.01
CPA LG ECSS	0.02	0.01
CPA LG EOUS	0.01	0.01
CPA LG ECUS	0.03	0.02
CPA ES EOSS	0.01	0.01
CPA ES ECSS	0.02	0.01
CPA ES EOUS	0.02	0.01
CPA ES ECUS	0.03	0.02
Centre of pressure displacement		
APA-COP EOSS (cm)	-1.53	1.57
APA-COP ECSS (cm)	-1.26	1.77
APA-COP EOUS (cm)	-2.08	1.26
APA-COP ECUS (cm)	-1.97	1.13
CPA-COP EOSS (cm)	-0.45	2.07
CPA-COP ECSS (cm)	-0.28	1.87
CPA-COP EOUS (cm)	-1.37	1.31
CPA-COP ECUS (cm)	-0.47	1.08
TO-COP EOSS (cm)	-1.24	1.65
TO-COP ECSS (cm)	-1.07	1.80
TO-COP EOUS (cm)	-1.98	1.29
TO-COP ECUS (cm)	-1.88	0.98

Abbreviations- BMI: Body Mass Index, APA: Anticipatory Postural Adjustment, CPA: Compensatory Postural Adjustment, LG: Lateral Gastrocnemius, ES: Erector Spinae, EOSS: Eyes Open Stable Surface, ECSS: Eyes Closed Stable Surface, EOUS: Eyes Open Unstable Surface, ECUS: Eyes Closed Unstable Surface, RMS: Root Mean Square, COP: Centre of Pressure, TO: Time of Perturbation; m: Metre, Kg: Kilogram, ms: Milliseconds.

from the time-aligned COP signal and included as a discrete time point in the repeated-measure analysis. TO-COP was included in the inferential analysis as well.

Statistical Analysis

Data analysis was performed using SPSS version 29.0 for Windows (SPSS Inc., Chicago, USA). The normality of the data was determined using the Shapiro Wilk test. Descriptive statistics (mean ± SD) were used to summarize baseline participant characteristics as presented in Table 1. Multiple repeated-measure multivariate analysis of variance (MANOVA) with factors (1) condition (four levels: EOSS, EOUS, ECSS, and ECUS) and (2) phase (two levels: APA and CPA) and muscles (LG, ES) were used to analyse RMS and muscle onset latencies variables of the recoded muscles. COP displacement variables were analysed using a multiple repeated measures ANOVA with within -subject factors : condition (EOSS, EOUS, ECSS, and ECUS) and time (APA window, TO, and CPA window). Post hoc analysis with Bonferroni correction was used for further pair-wise comparisons. When the assumption of sphericity was violated as assessed by Mauchly's test, Greenhouse-Geisser correction was applied. Effect sizes were reported as partial eta squared (ηp^2). Statistical significance was set at $p \leq 0.05$.

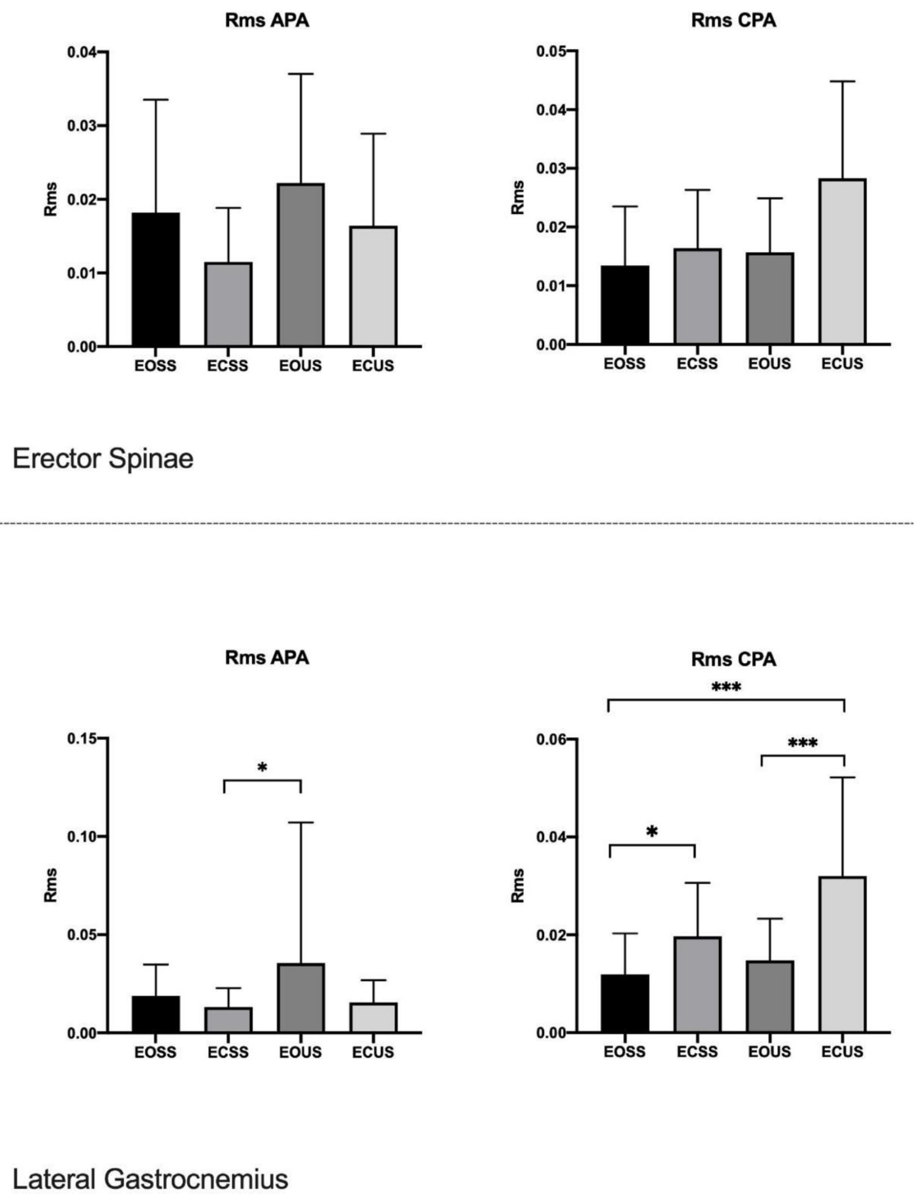

Figure 1. A: Erector Spinae activity during APA; B: Erector Spinae activity during CPA; C: Lateral Gastrocnemius activity during APA; D:Lateral Gastrocnemius activity during CPA. (APA: Anticipatory Postural Adjustments; CPA: Compensatory Postural Adjustments; EOSS: Eyes Open Stable Surface; ECSS: Eyes closed Stable Surface; EOUS: Eyes Open Unstable Surface; ECUS: Eyes Closed Unstable Surface). **p < 0.05; **p < 0.01; ***p < 0.001. RMS values are reported in arbitrary units (a.u.).*

Results

Muscle Activity

EMG: Root-Mean-Square (RMS)

There was no significant main effect of phase (APA vs CPA) on ES (RMS), $F(1,76) = 1.23$, $p = 0.27$, $\eta p^2 = 0.02$, and no significant phase × condition interaction, $F(3,76) = 0.30$, $p = 0.83$, $\eta p^2 = 0.01$ (Figure 1A & B). Similarly, LG (RMS) did not demonstrate a significant main effect of phase, $F(1, 76) = 0.05$, $p = 0.83$, $\eta p^2 = 0.001$. However, a significant phase × condition interaction was observed for LG RMS, $F(3,76) = 9.94$, $p < 0.001$, $\eta p^2 = 0.28$. Post hoc analysis revealed significant differences between ECSS and EOUS conditions during the APA phase (MD = -0.29, $p = 0.01$), and during the CPA phase between EOSS vs ECSS (MD = -0.25, p = 0.01), EOSS vs ECUS (MD = -0.44, $p < 0.001$) and EOUS vs ECUS (MD = 0.31, $p = 0.001$) (Figure 1C & D).

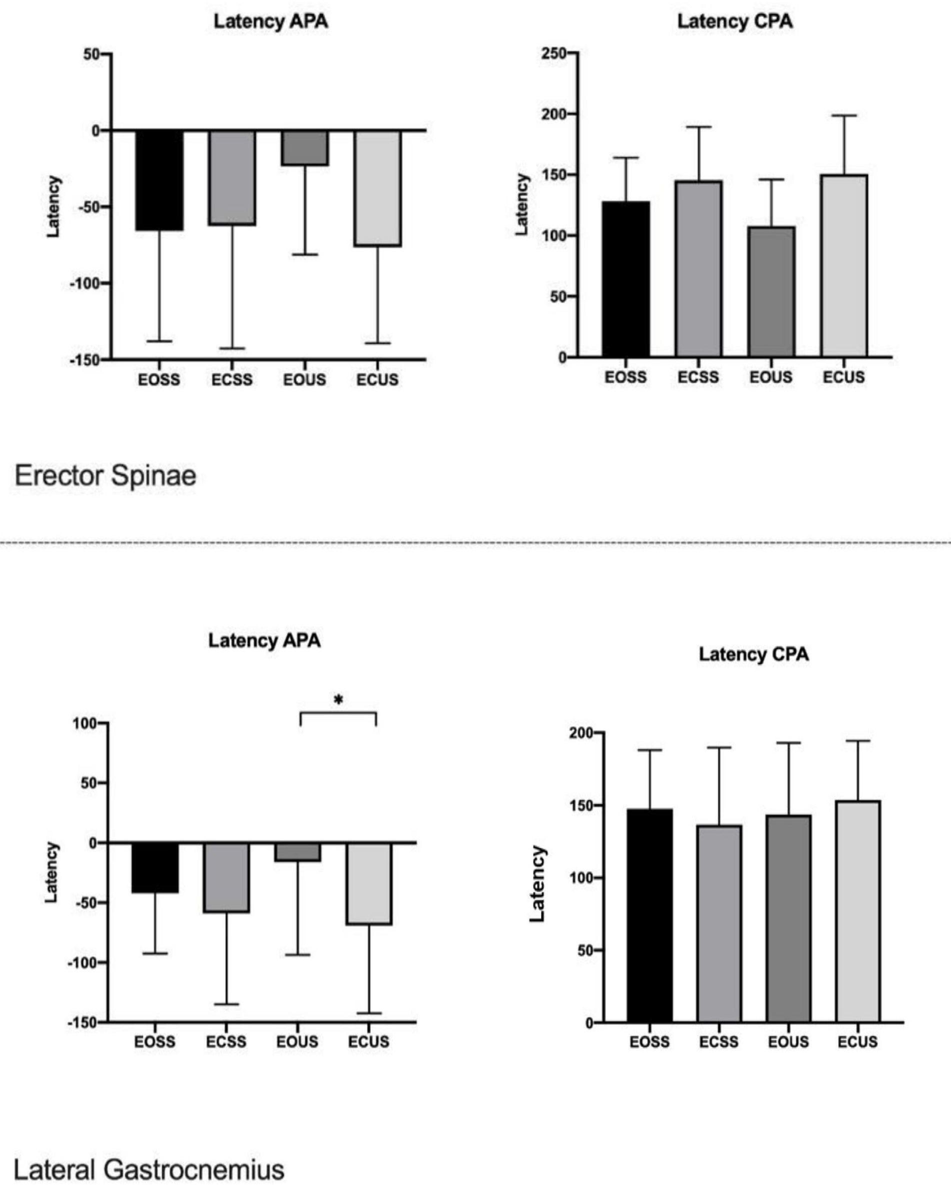

Figure 2. A: Erector Spinae Latency during APA; B: Erector Spinae Latency during CPA; C: Lateral Gastrocnemius Latency during APA; D: Lateral Gastrocnemius latency during CPA.(APA: Anticipatory Postural Adjustments; CPA: Compensatory Postural Adjustments; EOSS: Eyes Open Stable Surface; ECSS: Eyes closed Stable Surface; EOUS: Eyes Open Unstable Surface; ECUS: Eyes Closed Unstable Surface). **p < 0.05; **p < 0.01; ***p < 0.001. Latency values are expressed in milliseconds (ms).*

EMG: Latency

A significant main effect of phase was observed for ES latency, $F(1, 76) = 5.05$, $p = 0.03$, $\eta p^2 = 0.06$, whereas the phase × condition interaction was not significant, $F(3, 76) = 1.44$, $p = 0.24$, $\eta p^2 = 0.05$ (Figure 2A & B). In contrast, LG latency demonstrated a significant main effect of phase, $F(1, 76) = 653.54$, $p < 0.001$, $\eta p^2 = 0.90$, along with a significant phase × condition interaction, $F(3, 76) = 4.96$, $p = 0.003$, $\eta p^2 = 0.16$. Post hoc analysis indicated a significant difference between EOUS and ECUS conditions during the APA phase (MD = 53.15, $p = 0.01$) (Figure 2C & D).

Centre of Pressure

COP Displacement

There was a significant main effect (APA-COP, TO-COP, CPA-COP) on COP displacement, $F(2, 152) = 98.79$, $p < 0.001$, $\eta p^2 = 0.57$. Post hoc comparisons revealed

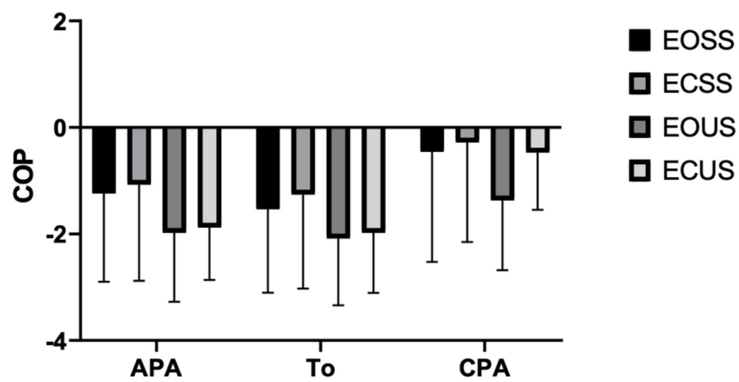

Figure 3. Mean centre of pressure (COP) displacement in APA, TO, and CPA under four sensory conditions. (Negative values represent forward COP displacement). *COP displacement is expressed in centimetres (cm).* (COP: Centre of Pressure; APA: Anticipatory postural adjustments; CPA: Compensatory postural adjustments; TO: Instant of perturbation; EOSS: Eyes Open Stable Surface; ECSS: Eyes closed Stable Surface; EOUS: Eyes Open Unstable Surface; ECUS: Eyes Closed Unstable Surface). *$*p < 0.05$; $**p < 0.01$; $***p < 0.001$.*

significant differences between APA vs TO (MD = -0.17, p = 0.001), APA vs CPA (MD = -1.07, $p < 0.001$), and TO vs CPA (MD = -0.89, $p < 0.001$). A significant time × condition interaction was also observed, $F(6, 152) = 2.98$, $p = 0.009$, $\eta p^2 = 0.11$ (Figure 3).

Discussion

The primary goal of the study was to investigate the influence of vision and somatosensory inputs on APA and CPA through selected muscle activity and COP changes when external perturbations were applied to the upper extremities. The findings of the study indicated that APA and CPA of the LG, along with displacements of the COP, differed significantly across various visual and surface conditions.

ES muscle plays a role in maintaining postural stability and generates the appropriate counterbalancing action to preserve equilibrium in the event of a perturbation[38]. The results showed that the activity of ES was not different in both APA and CPA. Also, similar findings were found in altered vision and changes in the stability of the surface. Nevertheless, that was consistent with previously reported results that found APA were generated in the thigh and leg muscles with no changes in the trunk muscles[39]. Although the outcomes of this study were comparable to those of a previous study conducted on healthy young adults who underwent a single session of training to maintain balance, future research is recommended to delve deeper into the muscle activity of the trunk muscles among older adults in relation to APA and CPA. A study conducted by Bouisset (2008) also emphasized that lower limb muscles play a crucial role in the coordination of APA and CPA[40]. These muscles are activated in anticipation of and in response to movements to stabilize the body and maintain postural equilibrium.

While examining the gastrocnemius muscle in the distal region, significant differences emerged between the APA and CPA across various standing conditions. Particularly, the gastrocnemius muscle activity demonstrated striking distinctions between conditions with visual input present and those without visual input on a stationary surface. However, these results were reversed in CPA, with all pairwise comparisons exhibiting substantial differences, except for the ECSS vs EOUS. Past research has shown that the generation of postural adjustments depends on visual or proprioceptive cues of the forthcoming perturbation[41]. Furthermore, research has demonstrated that when vision information is available, APA are produced in the trunk and leg muscles due to the accurate estimation of the timing of the perturbation to the body[42].

Contrary to muscle activity findings, the latency of ES was different between APA and CPA. Also, there was a significant difference during the APA and CPA phases in different conditions for gastrocnemius. The pairwise post hoc analysis showed a significant difference between EOUS Vs ECUS in the APA phase only. A previous study also reported that the latency of the ES and biceps brachii muscles across different conditions were significantly shorter in the eyes-open condition than in the eyes-closed condition for both muscles. This implies the importance of vision on APA and CPA postural stability in response to unpredictable postural perturbations[33].

The importance of vision in balancing the body is well understood and studied[43,44]. The deterioration in balance often results from challenged visual feedback which induces unnecessary body sway[45]. These body sways are found to be maximum in eyes-closed conditions. It has already been established in literature that in conditions where visual input is limited or altered, such as eyes-closed situations or low light environments, older adults exhibited greater difficulty in maintaining balance compared to younger adults[46].

It has additionally been shown that peripheral vision rather than focal vision adds to the support of a steady standing position, with body sway being impacted more during head/eye movements, than during truncal movements[47]. During eyes-closed conditions, CPA may be higher than APA due to unaccustomed disturbance in body posture, which induces perturbations and reciprocal activation of muscles as recorded by EMG activity. The current study showed that in CPA phase, the RMS value of LG was significantly higher in the eyes-closed condition than in the eyes-open condition. These results are consistent with the earlier reported studies which found that CPA is higher than APA when a movement is initiated[36]. Furthermore, the results showed that latencies were not different in proximal and distal muscles, while the muscle activity was different during APA and CPA. In contrast, previous studies have investigated the latency associated with changes in the visual inputs and determined that the APA exhibit reduced efficiency with a lesser magnitude and/or delayed latencies[37,41]. It has been found that to balance the body, a healthy adult requires a combination of all three sensory feedbacks in a fixed proportion with role of somatosensory being the highest (70%), vestibular (20%) and the vision (10%) in normal environment[48].

The role of altered somatosensory information in the control of perturbed posture is of special interest because many individuals with neurological conditions have diminished somatosensory information and are frequently exposed to external perturbations. For instance, people with diabetic neuropathy often experience greater body sway owing to diminished feet and ankle mechanoreceptors feedback than in healthy adults[49].

Alterations in somatosensory information in the current study were induced by unstable surface that produced body sway. Such altered somatosensory information resulted in a significantly higher RMS value of LG. The possible explanation for this observation was the fact that somatosensory information is the main feature in balance control[48] and it was not astonishing that adjustments in the proprioceptive information have influenced muscle activation patterns and COP relocations even in eye-open conditions. This result is in accordance with the past research[50,51].

In this study, information from two sensory systems, vision and somatosensory, was altered (ECUS) before applying external perturbations to the upper body of the subjects. The findings revealed that in conditions with altered somatosensory information and absence of vision, there was greater activation of muscles and COP displacement during the CPA phase. There are two possible explanations for this observation, the subjects in our experiment were in eye-closed conditions (ECSS and ECUS), which may have limited their ability to predict the upcoming perturbation induced by the release of the sandbag and it is well established that predictability of upcoming external disturbance against the body is a major factor in the generation of APA and subsequent CPA magnitude. Thus, it was observed that APA control was not seen in subjects who were exposed to external perturbations such as being hit by a ball in all the conditions in eyes closed environment[35]. Secondly, the subjects were standing on the foam surface which acts as an unstable surface thus the subjects are in unstable posture which is also consistent with the fact that the production of APA during unstable surface is lesser[52]. Since, APA itself generates internal motion which acts as a destabilizing force during unstable surface conditions[52]. In response to this internal motion, subjects in earlier studies produce a greater amount of CPA in order to restore the deranged balance of the body[35]. Thus, in this study, subjects were unable to produce anticipatory EMG activity which eventually resulted in large compensatory EMG activity.

Changes in COP displacement

In addition to the EMG analysis, COP was another measurement index used to assess postural stability. The COP changes at different time points were significantly different during APA, time of sandbag-hitting (TO), and CPA. The pair-wise comparison also showed a significant difference APA vs TO, APA vs CPA, TO vs CPA. COP displacement differed significantly across time points (APA, TO, CPA) and showed a significant time × condition interaction; post hoc comparisons indicated a significant difference between ECSS and EOUS. That was similar to a study by Laessoe & Voigt, (2008), researchers used the movable force plate to compare the postural stability among elderly and young participants, and they found that APA were used to overcome the perturbation event and the anticipatory COP displacement was higher under the dual task conditions in both groups[53]. In addition, numerous previous studies indicated that when vision was available, participants exhibited stronger APA activation and lesser latency period in the examined muscles[33,35,36,54].

The COP displacements were recorded in the forward direction (negative values according to the laboratory coordinate system) for all four conditions. The anticipatory displacement of COP at the moment of perturbation (TO) was smallest for the ECSS condition, followed by EOSS and ECUS, and largest for the EOUS; however, no significant pairwise differences were observed between conditions for APA-COP (all $p > 0.05$). On the contrary, previous studies showed backward displacement of COP when visual input was available, and the participant was expecting the perturbation[35,55]. A possible explanation for this observation is that during the EOUS condition, participants were able to visually anticipate the upcoming perturbation while being in a relatively unstable posture, leading to anticipatory muscle activation and corresponding changes in COP displacement. The magnitude of COP displacement after perturbation was highest for EOUS followed by EOSS and ECUS and it was smallest for ECSS condition, however no significant pairwise differences were observed between conditions for CPA-COP (all $p > 0.05$).

Although the vestibular system plays an important role in maintaining balance, it was not specifically targeted in this study. The experimental setup involved static standing with upper limb loading, which did not require significant head movement—thus limiting vestibular activation. Moreover, assessing vestibular contribution typically involves techniques such as head rotations or galvanic stimulation, which were beyond the study's scope. In older adults, degeneration of somatosensory receptors often shifts reliance toward visual and, to a lesser degree, vestibular inputs. Under conditions where both vision and surface stability are altered (e.g., ECUS), it is possible that vestibular inputs may play a role in postural control; however, this cannot be determined from the current dataset. Therefore, any interpretation regarding vestibular contribution remains speculative and requires confirmation through studies incorporating vestibular-specific assessments or manipulations[3,48].

However, the study had some limitations that needed to be addressed. First, the participants were aware of the direction and weight of the dropping sandbag. Future research could consider changing the direction of the catch with different weights. Second, although the perturbation was applied in the standardized manner using the same load and release procedure, the sandbag dropping speed was not instrumentally controlled. Manual release paradigms similar to the present study have been used in investigations of APA and CPA[4,39]; however variability in perturbation impulse cannot be entirely excluded. Therefore, interpretations of anticipatory and compensatory responses in the present study should be restricted to relative differences across sensory conditions rather than absolute measures of postural control efficiency. However, in the present study, the examiner practiced releasing the sandbag before the actual trial to substantially ensure as much similarity in speed as possible.

Also, the study included healthy older adults, so the findings cannot be generalized to this population with balance or neurological impairments. Future studies are recommended to investigate the influence of visual and somatosensory inputs on APA and CPA among older adults with motor deficits. That might assist in setting the stage for developing prevention strategies for postural control-related incidents among older adults.

Additionally, another important limitation of this study was the limited number of EMG recording sites, as muscle activity was recorded only from the ES and LG muscles. Although a key finding highlighted differential activation patterns between trunk extensor and lower-limb muscles, recording from these two muscles alone cannot fully characterize the complex multi-muscle trunk versus lower limb postural strategies involved in APA & CPA. Employing a more extensive muscle activation mapping-including additional trunk and lower-limb muscles with EMG-could provide more comprehensive understanding of neuromuscular coordination underlying postural control. Future studies are therefore encouraged to use more detailed neurophysiological measurements and broader range of muscles to further clarify these activation patterns. Finally, EMG amplitude data were not normalized to MVC. Although all comparisons were made within-subject and within-session, this limits direct comparison of EMG amplitude values with studies using normalized EMG signals.

Conclusion

This study demonstrated greater modulation of anticipatory activity in the LG compared with the ES in response to external perturbation, reflecting muscle-specific contributions to postural control under altered sensory conditions. This differential activation suggests that the LG demonstrated greater involvement in rapidly stabilizing the body in response to unexpected disturbances relative to the ES muscle. In addition, the study revealed that in conditions when the vision cues were not available with alternation of the support surface, the muscle activity and COP displacement were larger during the CPA phase.

The study's findings provide insight into the sensory and neuromuscular mechanisms underlying postural control mechanisms in older adults and may form the basis of future balance-training interventions. However, the effectiveness of such interventions requires confirmation through dedicated interventional studies.

Ethics Approval

The study was approved by the Institutional Ethical Committee of Jamia Millia Islmia, New Delhi (Approval No. 26/11/264/JMI/IEC/2019) and was conducted in accordance with the Declaration of Helsinki (1964) and its later amendments.

Consent to Participate

Written informed consent was obtained from all participants prior to enrolment.

Authors' Contributions

Adnan Kr Mohd: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft.; Sarah Parveen: Data analysis, Writing – review & editing.; Chhavi Arora Sehgal: Conceptualization, Supervision, Writing – review & editing; Syed Naznin Fatma: Formal analysis, Visualization; Fayaz Khan: Methodology, Resources; Mashael Al sobhi: Writing – review & editing, Validation; Md. Dilshad Manzar: Statistical review, Review & editing; Majumi M. Noohu: Supervision, Project administration, Writing – final approval. All authors read and approved the final version of the manuscript.

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References

1. Hyodo M, Saito M, Ushiba J, Tomita Y, Minami M, Masakado Y. Anticipatory postural adjustments contribute to age-related changes in compensatory steps associated with unilateral perturbations. Gait Posture. 2012 Jul;36(3):625–30.
2. Kerr A. Introductory biomechanics. Edinburgh: Churchill Livingstone; 2010.
3. Shumway-Cook A, Woollacott M. Motor Control: Translating Research Into Clinical Practice. In: Osteoporos Int. 2006.
4. Aruin AS, Latash ML. The role of motor action in anticipatory postural adjustments studied with self-induced and externally triggered perturbations. Experimental brain research. 1995 Jan;106(2):291-300.
5. Li X, Aruin AS. The effect of short-term changes in the body mass on anticipatory postural adjustments. Exp Brain Res. 2007 Aug;181(2):333–46.
6. Alexandrov AV, Frolov AA, Horak FB, Carlson-Kuhta P, Park S. Feedback equilibrium control during human standing. Biol Cybern. 2005 Nov;93(5):309–22.
7. Park S, Horak FB, Kuo AD. Postural feedback responses scale with biomechanical constraints in human standing. Exp Brain Res. 2004 Feb 1;154(4):417–27.
8. McIlroy WE, Maki BE. Changes in early ‘automatic’ postural responses associated with the prior-planning and execution of a compensatory step. Brain Res. 1993 Dec;631(2):203–11.
9. Bleuse S, Cassim F, Blatt JL, Labyt E, Derambure P, Guieu JD, et al. Effect of age on anticipatory postural adjustments in unilateral arm movement. Gait Posture. 2006 Oct;24(2):203–10.
10. Kanekar N, Aruin AS. The effect of aging on anticipatory postural control. Exp Brain Res. 2014 Apr;232(4):1127–36.
11. Kubicki A, Bonnetblanc, Petrement, Ballay, Mourey. Delayed postural control during self-generated perturbations in the frail older adults. Clin Interv Aging. 2012 Feb;65.
12. Woollacott MH, Manchester DL. Anticipatory Postural Adjustments in Older Adults: Are Changes in Response Characteristics Due to Changes in Strategy? J Gerontol. 1993 Mar 1;48(2):M64–70.
13. Horak FB, Henry SM, Shumway-Cook A. Postural Perturbations: New Insights for Treatment of Balance Disorders. Phys Ther. 1997 May 1;77(5):517–33.
14. Massion J. Movement, posture and equilibrium: Interaction and coordination. Prog Neurobiol. 1992 Jan;38(1):35–56.
15. Assländer L, Peterka RJ. Sensory reweighting dynamics in human postural control. J Neurophysiol. 2014 May 1;111(9):1852–64.
16. Chiba R, Takakusaki K, Ota J, Yozu A, Haga N. Human upright posture control models based on multisensory inputs; in fast and slow dynamics. Neurosci Res. 2016 Mar;104:96–104.
17. Fitzpatrick R, McCloskey DI. Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. J Physiol. 1994 Jul;478(1):173–86.
18. Hall LM, Brauer S, Horak F, Hodges PW. Adaptive Changes in Anticipatory Postural Adjustments With Novel and Familiar Postural Supports. J Neurophysiol. 2010 Feb;103(2):968–76.
19. Slijper H, Latash M. The effects of instability and additional hand support on anticipatory postural adjustments in leg, trunk, and arm muscles during standing. Exp Brain Res. 2000 Oct 16;135(1):81–93.
20. Hausbeck CJ, Strong MJ, Tamkei LS, Leonard WA, Ustinova KI. The effect of additional hand contact on postural stability perturbed by a moving environment. Gait Posture. 2009 Apr;29(3):509–13.
21. Lubetzky-Vilnai A, McCoy SW, Price R, Ciol MA. Young Adults Largely Depend on Vision for Postural Control When Standing on a BOSU Ball but Not on Foam. J Strength Cond Res. 2015 Oct;29(10):2907–18.
22. Van Humbeeck N, Kliegl R, Krampe RT. Lifespan changes in postural control. Sci Rep. 2023 Jan 11;13(1):541.
23. Nagai K, Yamada M, Tanaka B, Uemura K, Mori S, Aoyama T, et al. Effects of Balance Training on Muscle Coactivation During Postural Control in Older Adults: A Randomized Controlled Trial. J Gerontol A Biol Sci Med Sci. 2012 Aug 1;67(8):882–9.
24. Papegaaij S, Taube W, Baudry S, Otten E, Hortobágyi T. Aging causes a reorganization of cortical and spinal control of posture. Front Aging Neurosci [Internet]. 2014 [cited 2025 Nov 26];6. Available from: http://journal.frontiersin.org/article/10.3389/fnagi.2014.00028/abstract
25. Bernard-Demanze L, Dumitrescu M, Jimeno P, Borel L, Lacour M. Age-Related Changes in Posture Control are Differentially Affected by Postural and Cognitive Task Complexity. Curr Aging Sci. 2009 Jul 1;2(2):135–49.
26. Malcolm BR, Foxe JJ, Joshi S, Verghese J, Mahoney JR, Molholm S, et al. Aging-related changes in cortical mechanisms supporting postural control during base of support and optic flow manipulations. Eur J Neurosci. 2021 Dec;54(12):8139–57.
27. Mileti I, Taborri J, Rossi S, Del Prete Z, Paoloni M, Suppa A, et al. Reactive Postural Responses to Continuous Yaw Perturbations in Healthy Humans: The Effect of Aging. Sensors. 2019 Dec 20;20(1):63.
28. Granacher U, Bridenbaugh SA, Muehlbauer T, Wehrle A, Kressig RW. Age-Related Effects on Postural

Control under Multi-Task Conditions. Gerontology. 2011;57(3):247–55.
29. Rietdyk S, Patla AE, Winter DA, Ishac MG, Little CE. Balance recovery from medio-lateral perturbations of the upper body during standing. J Biomech. 1999 Nov;32(11):1149–58.
30. Roelofs JMB, De Kam D, Van Der Zijden AM, Robinovitch SN, Weerdesteyn V. Effect of body configuration at step contact on balance recovery from sideways perturbations. Hum Mov Sci. 2019 Aug;66:383–9.
31. Tokur D, Grimmer M, Seyfarth A. Review of balance recovery in response to external perturbations during daily activities. Hum Mov Sci. 2020 Feb;69:102546.
32. Claudino R, Dos Santos ECC, Santos MJ. Compensatory but not anticipatory adjustments are altered in older adults during lateral postural perturbations. Clin Neurophysiol. 2013 Aug;124(8):1628–37.
33. Zhang Z, Gao Y, Wang J. Effects of vision and cognitive load on anticipatory and compensatory postural control. Hum Mov Sci. 2019 Apr;64:398–408.
34. Merletti R. Surface electromyography: The SENIAM project. 2000 Jan 1;36:167–9.
35. Santos MJ, Kanekar N, Aruin AS. The role of anticipatory postural adjustments in compensatory control of posture: 2. Biomechanical analysis. J Electromyogr Kinesiol. 2010 Jun;20(3):398–405.
36. Santos MJ, Kanekar N, Aruin AS. The role of anticipatory postural adjustments in compensatory control of posture: 1. Electromyographic analysis. J Electromyogr Kinesiol. 2010 Jun;20(3):388–97.
37. Mohapatra S, Krishnan V, Aruin AS. The effect of decreased visual acuity on control of posture. Clin Neurophysiol. 2012 Jan;123(1):173–82.
38. Panjabi M, Abumi K, Duranceau J, Oxland T. Spinal Stability and Intersegmental Muscle Forces: A Biomechanical Model. Spine. 1989 Feb;14(2):194–200.
39. Kanekar N, Aruin AS. Improvement of anticipatory postural adjustments for balance control: Effect of a single training session. J Electromyogr Kinesiol. 2015 Apr;25(2):400–5.
40. Bouisset S, Do MC. Posture, dynamic stability, and voluntary movement. Neurophysiol Clin Neurophysiol. 2008 Dec;38(6):345–62.
41. Shiratori T, Latash M, Aruin A. The role of action in postural preparation for loading and unloading in standing subjects. Exp Brain Res. 2001 Jun 1;138(4):458–66.
42. Santos MJ, Aruin AS. Effects of lateral perturbations and changing stance conditions on anticipatory postural adjustment. J Electromyogr Kinesiol. 2009 Jun;19(3):532–41.
43. Onofrei RR, Amaricai E. Postural Balance in Relation with Vision and Physical Activity in Healthy Young Adults. Int J Environ Res Public Health. 2022 Apr 20;19(9):5021.
44. Tomomitsu MSV, Alonso AC, Morimoto E, Bobbio TG, Greve JMD. Static and dynamic postural control in low-vision and normal-vision adults. Clinics. 2013 Apr;68(4):517–21.
45. Terrier P, Reynard F. Importance of vision for minimizing postural sway evidenced through a battery of simple standing balance tasks and a chest-worn accelerometer. Gait Posture. 2017 Sep;57:327–8.
46. Borel L, Alescio-Lautier B, Léonard J, Régner I. Age-based stereotype threat effects on dynamic balance in healthy older adults. Front Syst Neurosci. 2024;18:1309158.
47. Berencsi A, Ishihara M, Imanaka K. The functional role of central and peripheral vision in the control of posture. Hum Mov Sci. 2005 Oct;24(5–6):689–709.
48. Petereka RJ. Sensory integration for human balance control. In: Handbook of Clinical Neurology [Internet]. Elsevier; 2018 [cited 2025 Nov 26]. p. 27–42. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780444639165000021
49. Nardone A, Schieppati M. Group II spindle fibres and afferent control of stance. Clues from diabetic neuropathy. Clin Neurophysiol. 2004 Apr;115(4):779–89.
50. Kasai T, Yahagi S, Shimura K. Effect of vibration-induced postural illusion on anticipatory postural adjustment of voluntary arm movement in standing humans. Gait Posture. 2002 Feb;15(1):94–100.
51. Slijper H, Latash ML. The effects of muscle vibration on anticipatory postural adjustments. Brain Res. 2004 Jul;1015(1–2):57–72.
52. Aruin AS, Forrest WR, Latash ML. Anticipatory postural adjustments in conditions of postural instability. Electroencephalogr Clin Neurophysiol Mot Control. 1998 Aug;109(4):350–9.
53. Laessoe U, Voigt M. Anticipatory postural control strategies related to predictive perturbations. Gait Posture. 2008 Jul;28(1):62–8.
54. Hwang JH, Lee YT, Park DS, Kwon TK. Age affects the latency of the erector spinae response to sudden loading. Clin Biomech. 2008 Jan;23(1):23–9.
55. Stapley P, Pozzo T. Does the centre of mass remain stable during complex human postural equilibrium tasks in weightlessness? Acta Astronaut. 1998 Aug;43(3–6):163–79.
56. Vennila K, Aruin AS. Postural control in response to a perturbation: role of vision and additional support. Exp Brain Res. 2011 Jul;212(3):385–97.