Dual task paradigms: Increased demand of task performance affects stability in functional activity and performance of visual- spatial task in normal healthy adults

by

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Dual task paradigms: increased demand of task performance affects stability during functional activity and performance in visuo-spatial task in healthy adults.

The purpose of the study was to evaluate effects of increasing balance task demands and visual tracking task demands, on stability and visual tracking performances, with possibility of any interaction among them. Twenty healthy participants were asked to perform various visual tracking tasks, with different attentional demands, while standing on various support surfaces. Two-way analysis of variance (ANOVA) with repeated measure design was performed to estimate significant effect. Support surface properties showed significant effects on stability measures but no significant effect on visual tracking performances were noticed. Significant effect of increasing visual tracking task demands on visual tracking performances were found. However, increasing visual tracking task demand did not show any significant effect on stability measures. Significant interaction effect was also found between surface properties and visual tracking task demands for stability measures. In conclusion, increasing balance demands effect stability and increasing visual tracking demands effect visual tracking performances.

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DEDICATION

My deepest and warmest thanks go to my parents and my siblings whose love and support has kept me going. I express my heartfelt gratitude and affection to my parents to whom I dedicate this thesis.

Chandrashekhar Yaduvanshi
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ABBREVIATIONS

AC: Amplitude Consistency

AP: Anterio- Posterior

CL: Closed Loop

COD: Coefficient Of Determination

COP: Center of Pressure

CTSIB: Clinical Test Of Sensory Interaction and Balance

DT: Dual Task

EC: Eye Closed

EF: Executive Function

EO: Eye Open

FSA: Foot insole pressure mapping system

ML: Medio- Lateral

OKR: Optokinetic Reflex

OL: Open Loop

RMS: Root Mean Square

SEM: Standard Error Mean

SOT: Sensory Organization Test

TA: Temporal Accuracy

UFOV: Useful Field Of View

VOR: Vestibule Occular Reflex

INTRODUCTION:

One-third of community dwellers over the age of 65 have experienced a fall (Nagamatsu, Liu-Ambrose, Carolan & Handy, 2009). Falling is a major healthcare concern due to related injuries, and also often leads to reduce activity levels. Recent studies have shown that environmental conditions and surface properties are not the only factors that increase the risk of falling, but an added cognitive load can also be the cause of a fall. Therefore, decline in cognitive abilities, especially executive function (EF), has been associated with an increased risk in falling, even in older adults who have no overt cognitive impairment (Lajoie, Teasdale, Brad & Fleury, 1993; Van Iersel Kessels, Bloem, Verbeek & Rikkert, 2008; Dingwell, Rodd, Troy & Grabiner, 2008; Hausdorff, Schweiger, Herman & Seligmann 2008).

Studies have also demonstrated that visual scanning and tracking tasks can also interfere with balance and standing stability. Normal visual processing of targets (stationary or moving) requires that the primary visual target be fixated on the fovea of the retina. If the image moves off the fovea (excessive retinal image slip), the visual resolution decreases quickly and visual blurring occurs, which can substantially limit one’s ability to process relevant information. Multiple processes are required to maintain foveation (focus) in order to accommodate and adapt to visual target motion, body and head motion, and background motion. Various technologies are being used to evaluate visual/gaze control and balance; for example, use of computers with large screen displays to produce opto-kinetic stimulation or full-immersion virtual reality systems. Studies have demonstrated that opto-kinetic stimulation and gaze shifts involving head rotation (and not just visual tracking with eye movement alone) can increase body sway and variation in walking rhythm (Mulavara & Bloomberg, 2002; Schubert, Bohner, Berger, Sprundel, Duysens , 2003; Duysens et al., 2008; Nagamatsu, Liu-Ambrose, Carolan & Handy 2009). Therefore, the aim of this study is to evaluate how visual-guided tracking tasks which require foveation along with head movements influence stability during standing on various surfaces or vice versa.

REVIEW OF LITRATURE

1. BALANCE CONTROL DURING STANDING:

Balance is a functional term, and its control is a subtle, multi-dimensional process. Sensing the state or threat to balance, and timely selection of appropriate motor strategies to correct movement errors, a sudden loss of balance or onset of stumbling is dependent on both the demands of a task and the environment, which can change substantially (Marin, Bardy, Baumberger, Fluckiger, & Stoffregen, 1999). For example, the characteristics of the support surface (being uneven, compliant, loose, slippery, etc.), the presence of crowd and obstacles can affect the likelihood of falling (Milisen et al., 2004). Thus, environmental factors substantially increase the level of uncertainty and fall risk.

A human's upright stance is controlled with the help of several senses. Important information is provided by vision, which normally works with cues from other senses, mainly from the vestibular, proprioceptive, and tactile somatosensory system (Szturm & Fallang, 1998; Van der Kooij, Jacobs, Koopman, Van der Helm 2001; Peterka, 2002; Creath, Kiemel, Horak & Jeka . 2002,;Rosengren et al., 2007; O'Connor & Kuo, 2009; Bonnet et al., 2010, D'Hondt et al., 2011).

In order to meet the challenges of task and environment, balance control systems require timely central organization and integration of multiple sources of spatial information. All primary sources of spatial information (visual, vestibular, and somatosensory propriocpeotrs and tactile) are required to establish internal and external spatial reference frames (egocentric and allocentric motions), and to distinguish visual background motion, visual illusions, and to support base characteristics and motion (Szturm & Fallang, 1998; Van der Kooij et al., 2001; Peterka, 2002; Creath et al. 2002; Rosengren et al., 2007; O'Connor et al., 2009, Bonnet et al., 2010; D'Hondt et al., 2011). Therefore, a number of methods have been used to challenge specific sensory systems to assess how well an individual integrates sensory information that is relevant for balance control. In regards to this, studies have assessed somatosensorial functions by altering support surface properties (Shumway-Cook & Horak, 1986; Cohen et al., 1993, El Kashlan et al., 1998; Allum, Zamani, Adkin & Ernst, 2002; Creath et al., 2005, Rosengren et al., 2006; Desai, Goodman, Kapadia, Shay & Szturm, 2009; D'Hondt et al., 2011). Whereas visual systems are challenged by the presence or absence of vision (Kuo, Speer, Peterka & Horak, 1998; Blackburn, Riemann, Myers & Lephart, 2003; Jeka Kieme, Creath, Horak & Peterka, 2004; Varncken et al., 2005; Rosengren et al., 2007), vision and vestibular systems are assessed by the movement of visual scenes (O'Connor & Kuo, 2009) or by moving the head with or without visual movement (Gill et al., 2001; Mulavara & Bloomberg 2003; Duysens et al., 2008; Desai et al., 2010).

Various clinical tests have been developed to assess balance performance, many of which manipulate different sources of sensory information (i.e., isolate the effects of vestibular signals versus visual and proprioceptive signals). The most advanced clinical test is the sensory organization test, or SOT (Rosengren et al., 2007), which includes a moving platform and a visual surround. This elaborate device operates to distort or eliminate visual and somatosensory signals (sway-referenced), and thus vestibular signals are required to maintain balance. This test includes measuring standing balance under six different sensory conditions. The first condition provides a baseline reference, and each of the subsequent five conditions systematically varies the sensory inputs, thereby increasing the level of sensory conflict.

Shumway-Cook and Horak (1986) have developed an inexpensive test for daily clinical practice based on the same principles as the SOT, known as the Clinical Test of Sensory Interaction and Balance (CTSIB). The CTSIB uses a compliant sponge as an unstable support surface to emulate the SOT in terms of somatosensory distortion, with an added advantage that it is not limited to the pitch plane; therefore, the disturbance could be multi-directional. A compliant sponge surface will modify the ground reaction forces under the feet (i.e., the compliant surface cannot completely reciprocate the normal body forces beneath the feet as the center of body mass moves). This technique can increase the magnitude and frequency of body sway (Shumway-Cook & Horak, 1986;; Allum et al., 2002, Creath et al., 2005; Desai et al., 2010). To prevent a fall, the individual must be able to sense and respond to this sway. Thus, increased demand on whole body balance occurs. Studies have demonstrated that body sway increases significantly when standing on a compliant sponge surface as compared to a normal fixed floor surface (Teasdale, Stelmach, Breunig & Meeuwsen, 1991; Kuo et al., 1998; Blackburn et al., 2003; Jeka et al., 2004; Creath et al., 2005). Such unpredictable change in support surface conditions requires the subject to rely more heavily on visual and vestibular inputs (Rosengren et al., 2007, Desai et al., 2010; D'Hondt et al., 2011) and The vestibular system is responsible for detecting forces the body is acting on, whereas the visual system detects the relative orientation of the body with reference to the environment, and in turn provides an external frame of reference for balance control (Szturm & Fallang, 1998; Rosengren et al., 2007; Desai et al., 2010; D'Hondt et al, 2011).

To keep the human body in a stable condition, it is important for all sensory and motor systems to be intact and coordinated. The brain receives, interprets, and processes the information from these systems to control our balance. Therefore, any situation that leads to a conflicting situation for any system could cause an unstable position. Apart from all the sensory inputs, balance can be challenged by executive function or cognitive tasks (Lajoie et al., 1993; Maylor, Allison & Wing, 2001; Van Iersel et al., 2008; Dingwell et al., 2008; Hausdorff et al., 2008). Therefore, dual task studies have been performed to better understand the interaction of higher functions and balance control mechanisms.

2. DUAL TASK MECHANISM:

Both mobility limitations and cognitive declines are common with aging, and these impairments affect the activities of daily living and increase the risk of falling and fall-related injuries. People with dementia often have gait disorders and also sustain an increased risk of falling (Laessoe, Hoeck, Simonsen & Voigt, 2008). The link between cognition and walking stability with the potential for falls is indeed being increasingly recognized (Liu- Ambrose, Katarynych, Ashe, Nagamatsu & Hsu, 2009). While cognitive deficits have been shown to increase the risk of falling, the specific nature of these deficits remains unspecified. Dual-task (DT) paradigms have increasingly been considered a classic way to assess the interaction between one's balancing condition, standing or gait, and higher function, or cognition. These studies quantitatively assess cognitive interference on gait performance during normal walking, as measured by dual-task methodology. For example, standing or walking while engaged in mental arithmetic, talking to a companion, tracking visual targets, or scanning a busy street for threats to safety are all required for an efficient standing or walking stability in a complex environment. Dual-task-related changes have been reported amongst different populations for a wide range of cognitive tasks, and in the various components of balance performance (Desai et al., 2010).

A number of studies have used a DT paradigm to evaluate the extent of sharing of information processing requirements between either motor or sensory tasks along with executive cognitive functions, for example, performing a motor-skill-related task while engaged in mental arithmetic, or in a memory task or any visual/auditory discrimination task, such as the Stroop test (color name written by a different color). DT methodology has a number of assumptions. These include (a) the central information processing capacity is limited, and (b) if two tasks that are performed together necessitate the use of more than the total capacity, the performance of either one or both will be reduced (Lajoie et al. 1993; Van Iersel et al., 2008; Dingwell et al., 2008; Hausdorff et al., 2008).

In a study conducted by Maylor et al. (2001), it was shown that stability is affected while performing a secondary cognitive task. These results were found after they studied participants engaging in an interaction of spatial and non-spatial memory task while concurrently maintaining a normal stable balance during standing. Stability was measured in the form of center of pressure (COP) variability and COP velocity, in an attempt to determine which aspect of balance control is affected by concurrent cognitive activity. Overall, 70 participants, aged from 20 to 70 years, participated. Brook's memory tasks were used for a cognitive challenge. This Brook's test consisted of spatial and non-spatial memory tasks. In the spatial version, the task was to listen to and then repeat back the location of a spoken digit on a sheet, which had a 4x4 grid. In the non-spatial task, the directions right, left, up, and down were replaced by the words "quick," "slow," "good," and "bad." Stimulus was presented verbally and participants had to answer in a grid. The number of correct answers was used as a dependent variable for spatial and non-spatial cognitive tasks. Tasks were performed while both sitting and standing. Force plate was used to record COP while standing. Average sway velocity and variability were used to index balance performance. Results showed that performance was higher overall in non-spatial tasks than in a spatial task. Their results demonstrated the significant effect of cognitive task type on participants' performances. The study also showed that cognitive load significantly affects the sway velocity and variability. There was no decreased in sway velocity when there was no cognitive task, but sway velocity increased when a cognitive task was given. The study also revealed that age also influences cognitive task performance and postural stability. The sway variability and velocity during a cognitive task were significantly greater in the medio-lateral direction for the older age group (70 years) than for any other age group. The results suggest that stability can be challenged based upon the type of cognitive task being performed.

A study conducted by Redfern, Jennings, Mendelson & Nebes (2009) also showed that diverted attention in a dual task is positively correlated with COP excursion (sway) in older age. In this study, 24 older adults (70-80 years) and 24 young adults (mean age 25.7 year) participated. Reaction time during cognitive task performance and postural sway in various positions were correlated with age. COP excursion (postural sway) was recorded in various standing conditions, as used in the sensory organization test. This postural sway was collected with the help of the Equitest platform used during six postural conditions, where visual scenes and support surface conditions were changed. For the cognitive function, two different tasks were presented on computer screens; one was a perceptual inhibition task and the second was a motor inhibition task. The perceptual inhibition task was given to assess participants' ability to maintain their attention, and the motor inhibition task was given to assess motor responses. For the perceptual task, a left- or right-pointing arrow was presented, and participants were asked to press the button where the arrow was pointing. This task consisted of two different conditions: congruous and incongruous. In the congruous condition, the spatial location of the arrow was the same as the direction of the pointed arrow. In the incongruous condition, the location of the arrow was opposite to the direction of the pointed arrow. The motor inhibition task also consisted of two different conditions. In the first condition, an arrow appeared in the center of screen, with right- and left-pointing arrows, and participants were asked to press the key towards the same direction as the pointed arrow. In the second condition, participants were asked to press the key on the side opposite of the direction of the pointed arrow. Their reaction time was used to calculate inhibition time for the given cognitive task, and was then correlated with COP excursion average (sway root mean square [RMS]) values in various standing positions. There was a moderate correlation between perceptual inhibition and COP excursion in sway referenced and eye open conditions. The main finding in this study was that perceptual inhibition is associated with postural sway in older adults.

3. RELATIONSHIP BETWEEN EYE- HEAD MOVEMENTS AND BALANCE CONTORL:

In demanding conditions, such as standing on compliant or irregular surfaces on which the tactile somatosensory system would provide unreliable information to the brain about base of support, the vision and vestibular system play a major role in providing necessary external spatial information. Vestibular and visual coordination is also very important for gaze control while moving in the environment and for tracking tasks. Gaze stability, or eye-head coordination, is defined as the ability to maintain fixation on an object of interest on the fovea of the retina during motion of (a) visual target, (b) visual surround, and (c) head/body motion in space (active or passive). Gaze stability is critical for the orderly processing of visual signals, specifically to prevent blurred vision. Gaze stability also indirectly impacts on balance. The inability to stabilize the gaze (maintain visual fixation) during relative motion between the head and visual surround will not only result in blurred vision, but also will result in perceived sensations of self motion, visual surround motion, and/or dizziness/vertigo. These illusions or sensations can destabilize standing balance. This is especially true when combined with body motion, whereby the target appears to move, or during the train illusion — the movement of a large background produces the sensation of self-motion. Eye-head coordination is the product of the interaction among vestibular inputs, visual inputs, and somatosensory inputs (such as neck proprioception).

The vestibular system has two major organs, the otolith organs and the semicircular canals. The otolith organs detect linear acceleration and orientation of the head with references to gravity. The semicircular canals detect angular acceleration, and de-acceleration then these forces acting on the head. Therefore, spatial information from vestibular sensors is important for balance control and eye-head coordination. Aging and other deficits of the vestibular system can cause a deficient vestibule-occular reflex (VOR), and thus an inability to track and fixate upon visual targets during head movements, resulting in considerable image blurring with consequent dizziness/nausea, oscillopsia and disorientation. The VOR is a mechanism for producing eye movements that counter head movements, thus permitting the gaze to remain fixed on a particular point. This in turn helps to stabilize the eye when the position of the head changes. In order to maintain gaze fixation at very high speeds, such as those produced during head and body movements, the VOR produces a compensatory action that moves the eyes in an equal and opposite direction in which the head is moving. The VOR is unable to maintain gaze stability at slow speeds, due to the inherent limits built into the transduction capabilities of the semicircular canals. The optokinetic reflex (OKR) system is complementary to the VOR and helps to stabilize the gaze at slow speeds. Whereas angular head motions stimulate the VOR, the OKR is stimulated by the actual movement of the visual background (or scene) across the retina during a head motion and measures the speed of the image moving across the retina. OKR is an eye response to large-scale movements of the visual scene. At a slower speed, OKR takes over from VOR; it operates by measuring the actual velocity of the image on the retina and causes the eye muscles to rotate the eye in the same direction as the retinal motion. For this reason, OKR is a closed-loop feedback system, whereas VOR is an open-loop feedback system, since eyes have no effect on the sensors, the semi-circular canals. A number of studies have shown that instability can be produced by exposure to moving visual scenes or background motion (O'Connor et al., 2009) or during head rotations while fixating on a target (Mulavara & Bloomberg 2002; Hollands, Ziavra & Bronstein 2004, Cinell, Ptla & Stuart, 2007; Duysens et al., 2008, Bonnet et al., 2010).

Rosengren et al. (2007) studied how balance control strategies change concurrent to the standing surface condition and visual condition change. Twenty older participants were asked to stand on a computerized dynamic posturography system, where various standing conditions had been given with an alteration in visual scenes. The COP was recorded to compute Anterio- Posterior (AP) sway displacement. Results showed not only the presence or absence of vision, but also that the movement of visual scenes influenced balance while standing. Their results showed that COP displacement was higher during a moving visual scene condition in comparison to a stable visual scene condition.

O'Connor et al. (2009) studied the effect of a moving visual scene on Medio-Lateral (MLs) and AP sway while standing. Oscillatory virtual visual scenes were presented to participants (who were 24 years old) in ML and AP direction. The visual scene consisted of a dark hallway with white rectangular tiles, which were used to create perturbation during task performance. Participants were presented with oscillatory perturbation of the visual field in the form of translational sinusoidal in the horizontal plane. Participants were instructed to maintain an even weight distribution between legs during the standing task. Both trials consisted of two amplitudes and two directions; sinusoidal perturbations in either the ML or AP direction were applied at amplitudes of 0 and 0.05 Hz randomized trial. The center of pressure was recorded to describe the standing stability. RMS of COP variability in AP and ML directions were computed from recorded COP movements, for both the standing trials. The RMS of COP signals in both directions were used to index balance during the standing trial. Their results showed that movement of the visual scene significantly induced increases in variability during periods of standing. Studies have also shown that visual scene movement influences stability in standing. Desai et al. (2010) also examined the effects of large gaze shifts, specifically those which required head and/or trunk rotation, on standing balance performance in older people with and without a history of falling. Participants performed the following tasks, first while standing on a normal fixed floor surface, then while standing on a compliant sponge surface: (a) control task, standing without any movement, (b) cyclic, rhythmic left and right head rotation to visual targets placed 120 degrees apart, and (c) cyclic, rhythmic horizontal trunk rotations of 45 degrees in each direction. Findings demonstrate a significant increase in the extent and amount of COP displacements during head rotation tasks as compared to during quiet standing conditions, especially on a sponge surface. In addition, there was a substantial increase in frequency of loss of balance while performing the tasks on the compliant sponge surface.

Hollands et al. (2004) and Cinelli et al. (2007) studied how rotation magnitudes of head, shoulder, trunk, and hip were influenced while performing a gaze reorientation task. Participants were asked to re-orientate their gaze on given cues, presented as various eccentricities, while standing on a normal surface. Their rotation magnitude results showed that larger head movement significantly influenced rotation magnitudes of body segments, which further altered segmental coordination; this is significant because coordination is very important for balance control.

Above discussed studies have also shown the effect of turning the head side to side, while the eyes are open, on postural balance. However, the question arises here, how can head movement cause such a challenge to balance control? Head movement is very important during functional activities in daily life. In many activities, head movement is required along with eye movements to track objects of interest. So, there is a sequence of eye-head coordination towards an object, but the postural balance system is also working when the desired object requires more attention or foveation. Thus, what would be the strategy to keep the body in a stable condition when all these functions are occurring? Additionally, how does this influence standing and walking balance strategies?

4. FOVEATION ALONG WITH HEAD MOVEMENT (SMOOTH PURSUIT) & BALANCE CONTROL:

Many activities of daily living require us to use fixation and foveation towards an object of interest in order to get information and respond appropriately (Land, 2006; Orban de Xivry & Lefevre, 2007). The fovea is a small circular region in the central retina that is densely populated mainly by cone photoreceptor cells. This area is specialized for visual acuity and high fidelity processing of image features; as such, foveation is the process of directing the fovea towards an object of interest. When a visual target of interest slips across and out of the region of the fovea, this will cause blurred vision for normal visual processing of detailed image features. So, it is important to minimize the amount of retinal image slip, which is made more difficult when the image is moving in space and when the head is moving in space as well. However, there are a number of mechanisms to control eye position and motion relative to a visual target (foveation) to compensate for a blurry scene.

Eye movements can help direct the fovea to an object of interest and compensate for disturbances that cause the fovea to be displaced from the target already being attended.

There are two main eye movements that we use in our daily life; one movement is saccade, and the second is smooth pursuit. Saccade and pursuit are two outcomes of a single sensorimotor process that aims at orienting the visual axis. Saccades are rapid ballistic movements of the eyes that abruptly change the point of fixation. The execution of a saccade helps us to quickly catch up with the target. In contrast with saccade toward stationary targets that only take the position error into account, catch-up saccade also needs to consider the relative motion of the eye with respect to the object of interest in order to be accurate. Moreover, saccades deteriorate vision during their execution, (i.e., large changes in the visual world occurring during saccades are not detected). Thus, the oculomotor system faces a trade-off between short epochs of poor vision and poor tracking. In sum, the smooth pursuit system needs to collaborate in order to improve tracking of a target that moves in an unpredictable way (Krauzlis, 2004). Therefore, smooth pursuit movements help to pursue the movement of object, and that in turn keeps the image of the object fairly and precisely on the fovea. To maintain a sense of perceptual spatial stability, despite self-motion, is an important requirement for successful spatial orientation. For this, the brain has to discern sensory signals due to the observer's own activities from others that arise from changes in the external world. Smooth pursuit allows us to stabilize the image of a selected object on, or close to, the fovea in order to make use of the advantages offered by foveal vision.

The inevitable consequence, however, is that the images of all other objects (the ‘‘visual background’’) will move on the retina at a speed corresponding to the eye rotation carried out. This kind of eye movement, induced by retinal image motion, must not be mistaken for movement of the world around us. Otherwise, our concept of a stable world would be lost. Therefore, the pursuit system tries to null the retinal slip of an object. Pursuit is modified by ongoing visual feedback and requires sensory information from the vestibular sensory organ during head motion, namely the vestibular-ocular reflex (VOR) and opto-kinetic reflex (OKR) system, to minimize retinal slip.

The neural circuitry underlying smooth pursuit is an object of debate. While certain studies (Thier & Ilg, 2005; Orban de Xivry & Lefevre, 2007) suggest that the primary visual cortex sends information about the target to the middle temporal visual cortex, and the processing of motion in this area is necessary for smooth pursuit responses. A region of cortex in the frontal lobe, known as the frontal pursuit area, responds to particular vectors of pursuit. The superior colliculus also responds during smooth pursuit eye movement. These two areas are likely involved in providing the GO signal to initiate pursuit, as well as selecting which target to track. The GO signal from the cortex and the superior colliculus is relayed to several pontine nuclei, including the dorsolateral pontine nuclei and the nucleus reticularis tegmenti pontis. The pontine nuclei projects to the cerebellum, specifically the vermis and the paraflocculus. These neurons code the target velocity and are responsible for the particular velocity profile of pursuit. The cerebellum, especially the vestibulo-cerebellum, is also involved in the online correction of velocity during pursuit. The cerebellum then projects to optic motoneurons, which control the eye muscles and cause the eye to move.

Studies have also shown that smooth pursuit is made more difficult when head movements are also required, as when visual targets move large distances and eye movements alone cannot track the target (Land, 2006; Orban de Xivry & Lefevre, 2007). Unpredictable head movements that occur during loss of balance and stumbles (i.e., negotiation differences of outdoor terrains) will affect the availability of the retinal image of visual targets. This will, in turn, cause an increase in the spatial attentional demand of the smooth pursuit system.

Not many studies have used smooth pursuit task in during standing but walking was included in quite a few studies, One of that study, Duysens et al. (2008) studied how trunk and head turns for gaze orientation influence body sway during walking, which challenged stability in normal healthy adults. For the study’s purpose, 12 healthy adult participants walked on a treadmill (1m/s) while following a moving dot along a horizontal line. This task required participants to fix their gaze and track the target by rotating their eyes, then head, and then trunk for different amplitudes, up to 25 degree (0, 5,10,15,20, and 25 degrees). The visual targets were presented on different excursions (0, 5, 10, 15, 20, and 25 degrees) in each direction. The visual target was a laser-projected red dot (2 mm in diameter) on a white screen. The target made a side-to-side (right and left) movement in a sinusoidal pattern, with a frequency of 0.125 Hz. Participants were asked to fixate their gaze and track the target on a given excursion for at least three side-to-side movements. Visual tasks need to be performed in three different conditions, thus the first one was an eye gaze condition. In this condition, participants had to horizontally track a moving red dot on the screen without any head and shoulder movements. In the second condition, participants tracked a moving dot with their head only, without moving their eyes and shoulder. In the third condition, the trunk was used to track a red moving dot without any eye or head movement. COP was quantified from the instrumented treadmill. Sway amplitudes of this COP were measured in the AP and ML direction to further define body displacement in AP and in ML directions. Their results showed that, in both AP and ML direction, the head rotation task caused more sway than during the eye task condition; in the ML direction, the head-tracking (19±11 mm) task caused more COP movement in comparison to the eye tracking (16±8) task. However, in the AP direction, the COP sway was 13±5 mm in head condition and 12±5 mm for eye condition.

Another study found an interesting fact, that a cognitive load can influence the smooth pursuit function. Meyer et al. (2007) studied an interaction between cognitive performance and gaze stability during visual tracking tasks. Their study was designed to examine whether or not cognitive load influences the smooth pursuit mechanism. Their results showed a decrease in smooth pursuit gain during cognitive task performance. In this study, both light and heavy cognitive task loads were included, such as a counting backwards task in step of seven and thirteen, respectively. Participants were also seated in a comfortable chair in a dark room, 1.2 m away from a screen where a white dot was presented. Participants were then instructed to follow the white dot as quickly and as accurately as possible as the dot moved in a horizontal sinusoidal pattern and performed prosaccade and antisaccade tasks. For the reflective eye movement (prosaccade) task, participants were instructed to follow a centralized dot that disappeared and reappeared at 20 degrees from the central position, and reappearance was random and could appear on either the right or left side. For voluntary (antisaccade) eye movements, participants were instructed to look opposite of the presented dot side before any trail eye movements were calibrated for saccadic latencies. In each condition, prosaccade and antisaccade, participants had to perform two eye tasks, one that was predictive in direction with a temporal uncertainty mean direction and amplitude of target that was known, while the target's movement was uncertain. The second task was predictive in direction and time; the target reappeared at 20 degrees (right or left) after a fixed disappearance frequency. In these two conditions, participants had to perform three tasks that consisted of no cognitive task, a control task, and a light cognitive load, which was a backward counting task from 7, and a heavy cognitive load which was backward counting from 13; participants had to answer clearly and correctly. Saccade latency and accuracy were calculated for each task. Latency was defined as the delay time occurring between each target jump and saccade. Accuracy was defined as the ratio of saccade amplitude divided by the target displacement amplitude x100. Smooth pursuit gain was also calculated by the ratio of average eye movement velocity and average target velocity. The comparison of the latency between prosaccade (involuntary) and antisaccade (voluntary) tasks showed the highest latency for predictive direction with temporal uncertainty and predictive direction and time tasks. The accuracy result showed that the prosaccade task had more accuracy than antisaccade tasks and that further participants showed more accuracy in the control task in prosaccade eye condition. Accuracy was similar for light and heavy cognitive loads, in both prosaccade and antisaccade conditions. Median values showed lesser latency and higher accuracy in the control task, as compared to during the cognitive load. Smooth pursuit gain also decreased during performance of the cognitive load. There were no significant differences in cognitive load conditions on involuntary and voluntary eye conditions. Median results also showed that latency increased and accuracy decreased from prosaccade to antisaccade conditions.

Another study found that if the state of balance were challenged it would influence visual task performance, which requires foveation and mental workload (Yu, Yank, Villard & Stoffregen, 2010). In this study, the authors have examined the relationships between visual task performance and body sway while standing posture is challenged. They also obtained the measure of cognitive load associated with visual vigilance tasks. Nine crewmembers (aged 26-60 years) participated in the study and performed two visual tasks (easy and hard) while standing on a force plate. Balance was challenged by the state of sea, and data were collected both during calm sea states (unchallenged balance) and during rough sea states (challenged balance). Visual tasks were presented on a computer screen while participants stood on a force plate. Visual tasks consisted of neutral, easy, and hard visual vigilance tasks. In the easy task, participants were given one pair of lines, which differed in vertical length (left visual angle 1.95˚ and right 2.35˚); and in the hard visual task, the length of presented lines was quite similar (left 1.95˚ and right 2.12˚); in the neutral visual task, both lines were the same length. There were 60 stimuli in each task, of which 40 were neutral and 20 were easy or hard visual tasks that challenged speed and accuracy in visual task performance.

Responses, neutral or critical signals, and COP variability were recorded during task performance. Visual perceptual sensitivity (d′ value) was calculated by combining hits and false response. The magnitude of postural movements was assessed by the standard deviation of the COP displacement in both the AP and ML direction. Their results showed that visual task performance differed significantly between easy and hard tasks. The grand mean of visual performance, when balance was challenged differed from when it was non-challenged condition. This indicates that visual performance was reduced when state of balance was challenged. This result also shows that an increased workload is also associated with balance conditions, grand mean for balance challenged conditions and for non-challenged conditions. The study found more body movement in both AP and ML directions when balance was challenged, as compared to unchallenged conditions. The grand mean of AP variability (2.75 cm/s) during balance challenges was greater than during unchallenged conditions (0.975 cm/s). The grand mean of ML variability (1.65 cm/s) during balance challenges was greater than unchallenged conditions (0.550 cm/s). The study revealed a relationship between visual task performance and balance, but in this study the author presented a visual task and balance condition in a moving ship where the computer screen was also moving with the same thrust as was given to challenge balance conditions. During rough seas, it is believed that water was giving a great thrust to the ship, so it is doubtful that recorded COP displacement was only due to body sway and not because of underneath thrusts given by water. During task performance, head movements were also influenced by unpredictable ship motion on rough seas, and this could have caused a decrease in visual performance and increase in COP excursion.

A number of recent studies have used computer-based programs to probe and evaluate visual attention and to process speed (Green & Bavelier, 2003). Visual attention and processing speed require both foveal and peripheral search mechanisms, as well as the ability to select relevant information and ignore (discriminate) irrelevant information with respect to an instruction (Bennett, Gordon & Dutton, 2009). The ability with which attention is distributed across the visual field can be measured using a visual search task, for example, using the Useful Field of View paradigm (UFOV) (Ball et al., 1988; adapted by Green and Bavelier et al., 2003). The UFOV test was developed to find age-related changes in visual perception and reaction (Bennett et al.). UFOV is the visual area over which information can be extracted at a brief glance without eye or head movements. Generally, UFOV size decreases with age, most likely due to decreases in visual processing speed, reduced attentional resources, and less ability to ignore distracting information. UFOV performance is correlated with a number of important real-world functions, including risk of an automobile crash. Performance can be improved by computer-based training. The traditional UFOV assessment is a computer-based visual test containing three subtests: a). Processing Speed: Determines a person's threshold for discriminating stimuli presented in central vision. b). Divided Attention: Same as Subtest 1 but with the addition of a concurrent peripheral target location task. c). Selective Attention: Same as Subtest b but with the addition of distracters. The threshold scores are combined to produce an overall performance score.

These studies have revealed that visual tracking tasks that require head movement have a significant impact on the body's stability, whether in standing or walking mode (Mulavara & Bloomberg, 2002; Schubert et al., 2003; Duysens et al., 2008). Although these studies have discussed how eye-head movement influences stability during standing and walking, how this coordination changes or influences stability when there would be changes in cognitive challenges and activity surface properties needs to be further studied. In our everyday life, there are many situations where we are required to obtain visual information from an object, which in turn requires cognitive capability, for example, during shopping, driving, and reading. These tasks require visual attention to perform, and this information always creates some load on our cognitive system. Therefore, it is important to understand how eye-head movement influences visual attention and/or the requirement of foveation.

STATEMENT OF PROBLEM:

DT studies have revealed that cognitive load, visual tracking, and surface properties have an influence on balance mechanisms during standing. Studies have further revealed that surface conditions influence the body's center of pressure, which further challenges body stability during activities. Studies have also revealed that head movements influence stability and gait in normal human beings (Schubert et al., 2003; Duysens et al., 2008). Eye movements with head stationary have been studied in ample research. Smooth pursuit is also required to track moving vehicles, during shopping, while looking for a person etc., but less work has been done on gaze control tasks while the head and/or body is moving and its effect on standing or walking.

However, previous studies have confirmed the existence of an interaction between physical and cognitive loads including visual scanning to acquire information. To challenge cognitive ability, studies have chosen memory task, planning, arithmetic problems, and Stroop tasks, but few studies have used a task that requires attention towards a task with foveation and head movement. To that end, we need to develop such a paradigm, which will be quite similar to what we perform in day-to-day life whether we are outside or inside the home, walking or standing, on a hard surface or a compliant surface. The role of attention in smooth pursuit performance is complex and not truly understood, but this eye movement requires foveation to track a desired object, thus requiring attention towards an object. Therefore, any blurring or lack of attention could cause problems in visual processing and further in body stability.

Thus, the primary goal of the present study is to examine smooth pursuit performance and stability during functional activities when levels of difficulty increased in both tasks (visual and physical).

PURPOSE:

Many daily activities require visual tracking tasks that are concurrent with balance and mobility tasks. Smooth pursuit tracking of moving targets not only requires eye-head coordination, but also requires cognitive function to execute the task. Therefore, the purpose of this study is to examine the interaction of visual tracking tasks incorporating active and passive head movement and dynamic balance processes during standing tasks.

OBJECTIVE:

The main objective of this study is

1. To examine the effects of increasing balance demand on visual tracking performances as well as on stability measures (COP excursion & trunk excursions).
2. To examine the effects of increasing visual tracking demands on visual tracking performances as well as on stability measures.
3. To examine the effects of interactions, in between balance demands and visual tracking demands, on trunk sway, COP excursion, and visual tracking performance.

HYPOTHESIS:

1. Increased balance demands will decrease visual tracking performance and also decrease stability by increasing body sway parameters (COP and trunk excursions).
2. Increased visual tracking demand (foveation) will decrease visual tracking performance and decrease stability by increasing body sway parameters (COP and trunk excursions).
3. There will be no interaction between balance demands and visual phase tracking demands on stability measures or visual tracking performance.

Balance demands included standing on fixed and compliant sponge surfaces, and visual tracking conditions included open loop tracking, closed loop tracking and anti-phase tracking, with respect to head movements.

METHODOLOGY:

PARTICEPANTS:

Twenty healthy adult participants, age 20 to 40 years, were recruited for this study via advertisement to students and staff at the University of Manitoba and Health Sciences Centre. Fifteen male and five female participants were participated and mean age was 28 years. Participants with a history of neurological and musculo-skeletal disorder, for example stroke, spinal or head injury, any mental disorder, muscular dystrophy, lower limb joint surgery, low-back ache and uncorrected visual impairments, were excluded from the study. Regarding the musculo-skeletal disorders, any history has given prime importance, and observational screening was also carried out for any obvious deformity, restriction of movement, or any muscle weakness. Participants were fully informed about the procedure, and informed consent was obtained before participation in the study. The University of Manitoba Health Research Ethics Board has approved the study.

DATA RECORDING AND MEASURING INSTRUMENTS:

1. Visually guided tracking software & In-Air mouse:

A custom-made computer visual tracking task has been developed in which a circular target is presented on a 32-inch computer monitor. The visual target is programmed to move from the left to right edge of monitor, in a sinusoidal pattern on a horizontal trajectory. For complete details see the Task protocol below. Participants were positioned approximately 100 cm from the monitor.

An In-Air mouse was used to interact and control the computer visual tracking task. It was a commercial computer mouse, which uses a bi-axial gyro to detect the mouse angular motion and thus permits its rotation to control the position of the computer cursor or game sprite/avatar. The mouse was attached to a lightweight Helmet and thus allows head control of computer cursor motion (see figures 1 & 2).

The visual tracking software, in addition to displaying a moving visual target, was synchronously recorded to file (80 Hz) the coordinates of the moving visual target and the mouse cursor coordinates (i.e., left-right head rotation, about the vertical axis).

2. FSA pressure mapping System:

For all standing activities, vertical foot-ground forces were recorded using a FSA pressure mat (Vista Medical, Winnipeg). The pressure mat was 53 cm^2 and contained an array of 256 sensors, each with a surface area of 2.8 mm. The sensors were calibrated from 0 to 6 PSI, 12-bit resolution. Each sensor in the mat array was sampled at 30 Hz. Each sensor in the insole array was sampled at 30 Hz. An instantaneous position of center of foot pressure (COP) was computed by the FSA software (version 4.2) and recorded along with forces.

3. Electromagnetic sensor for trunk position:

A DC magnetic motion tracking system Motion Star (Ascention Tech., USA) with 10 mm sensor was used to record 3-D linear position and 3-D angular orientation of the trunk segment.

The miniature sensor was attached with surgical tape to the skin of each participant at the second thoracic vertebra. This has provided linear position signals for the sagittal and coronal plane. AP movement represents linear movement in sagittal plane, whereas ML movement represents linear movement in coronal plane. The roll and yaw movements were recorded. The roll is defined as the angular displacement of the trunk in the frontal plane and yaw is defined as rotation around vertical axis. Sampling rate was 130 Hz.

4. Sponge pad to modify support surface:

A foam sponge pad (53.8 cm X 53.8 cm X 10.16 cm) was used for standing. A 25.4 cm X 40.64 cm X 1.91 cm wooden board was placed on the top of the sponge pad where the pressure mat was placed and the participants were stood. So the sequence was, from top, pressure mat, wooden board, and sponge pad. Two grades of sponge pads were used to counterbalance the effect of differences in body weight. A low support (53.8 cm X 53.8 cm X 10.16 cm) sponge pad, with a density of 16.016 kg/m^3 and a 25% indentation force deflation (IFD) of 6.82 kg was used for people who weigh less than 55 kg. A medium support (53.8 cm X 53.8 cm X 10.16 cm) sponge pad, with density of 22.66 Kg/m^3 and 25% IFD of 13.64 kg, was used for people who weigh more than 55 kg.

PROCEDURE AND TASK PROTOCOLS:

Participants were asked to perform 5 visual tasks, consisting of eye open, eye closed and three visual tracking tasks, with different attention demands, open, closed loop, and anti visual tracking. The tasks were with three different physical loads of sitting, normal standing , and sponge standing. During sitting, participants were asked to perform only three visual tracking tasks. For this purpose, a computerized visual tracking task was developed and used similar to the studies of Roerdink, Ophoff, Lieke, Peper, and Beek (2008), Carey, Kimberley & Lewis (2002), Andersen Hammond, Shay, and Szturm (2009). A custom software program was created to move an on-screen cursor (large bright-colored circle) from the left to right edge of the monitor in a predictable, sinusoidal fashion. Frequency of the cursor motion was set at 0.5 Hz, and amplitude was full screen, thus one full movement cycle took 2 seconds, which is considered a slow head movement. Eyes open and standing on normal and sponge surface was used as a controlled condition for physical load, and the sitting condition was used to minimize balance requirement so that visual tracking load could be differentiated or identified.

VISUAL TRACKING TASKS:

This included open loop and closed-loop and anti-visual tracking tasks.

1. Open-loop visual tracking task: The participants were asked to rotate the head in concert with motion of the target cursor. This required peripheral and central oculo-motor following mechanism, which did not require continuous foveation of the moving cursor except at reversal points (i.e., when moving [target] cursor reaches left edge and right edge of screen).

2. Closed-loop visual tracking task: This task required foveation to be successful in completion of task. In this task, two cursors of different colors appeared on the monitor. One was the target cursor as in open-loop condition moving sinusoidally left to right. Motion of the second cursor was slaved to head rotation (via head tracking mouse: Figure 1). The task goal was to overlap the two cursors during motion from left to right edge of the monitor. Thus the participants were required foveation in order to determine the amount of overlap (error) between the target cursor and the head cursor. A control trial with no visual tracking was also performed to find visual influence.

3. Anti-visual tracking task: In this task, participants were asked to move their head in opposite direction of moving target cursor (red circle) on screen. This task was used to see whether participants required any foveation or not to complete tracking tasks.

PHYSICAL TASKS:

Physical tasks included sitting, standing on normal and sponge surfaces.

1. Participants sat on a chair without back support and performed only visual tracking tasks.
2. Participants stood on a normal fixed floor surface and performed eye open, eye closed and visual tracking tasks for 30 second.
3. Participants stood on a compliant sponge surface. Use of a compliant surface modified the ground reaction forces under the feet (i.e., the compliant surface cannot completely reciprocate the normal body forces beneath the feet as the center of body mass

moves). This increased the magnitude and frequency of body sway and thus increased balance demand.

Participants were fitted with a head-tracking mouse. Participants were positioned on the treadmill (to provide a safer environment with handrails) two meters away from the computer monitors. We have used a large screen (32 Inches). With this set-up, participants were required to produce 60 degrees of head rotation when performing visual tracking tasks. In total, 10 standing tasks were performed, which took approximately 30 minutes to complete.

Figures: Illustration of Head-mounted mouse and smooth pursuit task set-up

Figure: 1

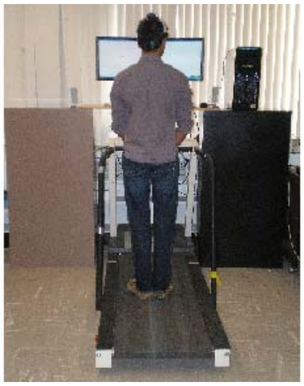
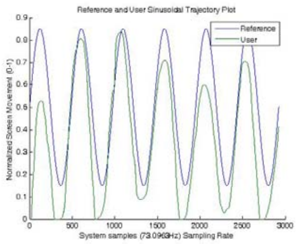


Figure: 2

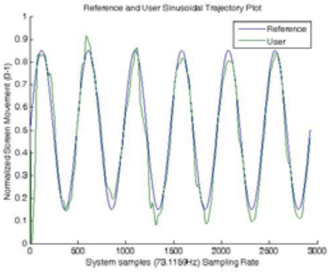
Figure 1: In-Air mouse adapted for use for therapeutic tele-gaming. The mouse is attached to a helmet and thus allows head control of computer cursor motion.

Figure 2: This demonstrates a visual tracking task set-up. Participant stands on a normal treadmill, with two side support railings. Three flat monitors are placed at eye level to stretch display screen. Monitors are connected by a CPU. The Air mouse is placed on the helmet which allows controlling the game by head movements.

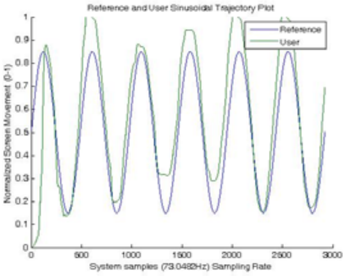
Figures: Illustration of visual task performance during standing on various surfaces.



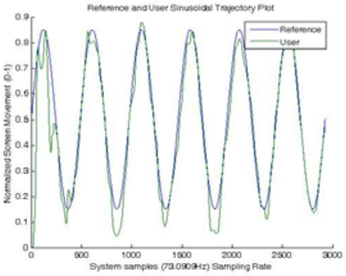
3. Open loop (no-foveation) smooth Pursuit task standing on normal Surface



4. Closed loop (foveation) smooth pursuit Task standing on normal surface



5. Open loop (no-foveation) smooth pursuit Task standing on Sponge surface.



6. Closed loop (foveation) smooth pursuit Task standing on sponge surface.

DATA ANALYSIS:

Independent variables:

1) Visual tracking – Three levels
    - a. Open-loop visual tracking
    - b. Closed-loop visual tracking
    - c. Anti-visual tracking

2) Physical tasks demands — Two levels
    - a. Standing fixed surface
    - b. Standing compliant sponge surface

Dependent Variables:

Visual task performance measure:

During visual tracking task, the following parameters were computed.

- a. Coefficient of determination (COD) was used to index performance of visual tracking task.
- b. Temporal accuracy at right and left turning points
- c. Amplitude consistency at right and left turning points

The computer tracking software was instrumented with an assessment module, which generated a logged game file to record (80 Hz) the following signals:

Coordinates of the reference tracking cursor and coordinates of the second cursor slaved to head rotation. This was directly related to head motion. These parameters were used to compute target cursor position and head position during both open- and closed-loop tracking tasks. The Coefficient of Determination (COD) between the target reference trajectory and the actual head motion was computed with a sine wave curve-fitting program. Temporal accuracy quantified as follows: the time to maximum and minimum points of each head movement cycle were subtracted from the time of the respective target cursor maximum and minimum. Average temporal accuracy (ms) of the turning points (maximum and minimum for all cycles) were computed.

Physical task performance measures:

1. *Index of stability measure in standing:*

The center of pressure (COP) is the point at which the force is acting to keep the body in equilibrium, thus in stable position, COP occurs in-between the feet. Therefore, any alteration in force application, due to surface property or unequal weight distribution, can alter the position of COP, and this represents unstable condition where working forces are not the same. The quantification of COP position has often been used as a measure of stability (Hunter & Hoffman, 2001; Schubert et al., 2003; Rosengren et al., 2007, Duysens et al., 2008; Redfern et al., 2009; Desai et al., 2010; Yu et al., 2010). The variability is often assumed to be deleterious, reflecting the presence of unwanted noise in a physiological system**.** The following variables will be computed from the recorded COP position signals in the AP and ML direction.

I. <u>Peak-to-peak COP excursion</u>: The maximum and minimum value of COP excursion in x-y plane.

II. <u>Path length:</u> It represents the total distance covered by COP (total sway path) divided by the duration of the sampled period and constitutes a good index of the amount of activity required to maintain stability (Santos, Delisle, Larivière, & Plamondon, 2008). This is the most reliable outcome parameter that measures postural stability (Lafond, Corriveau, Hebert, & Prince, 2004).

III. Rout mean square (RMS) of COP excursions: The RMS indicates the magnitude of COP amplitudes. The RMS–COP is a reliable parameter to evaluate the postural steadiness (Lafond et al., 2004).

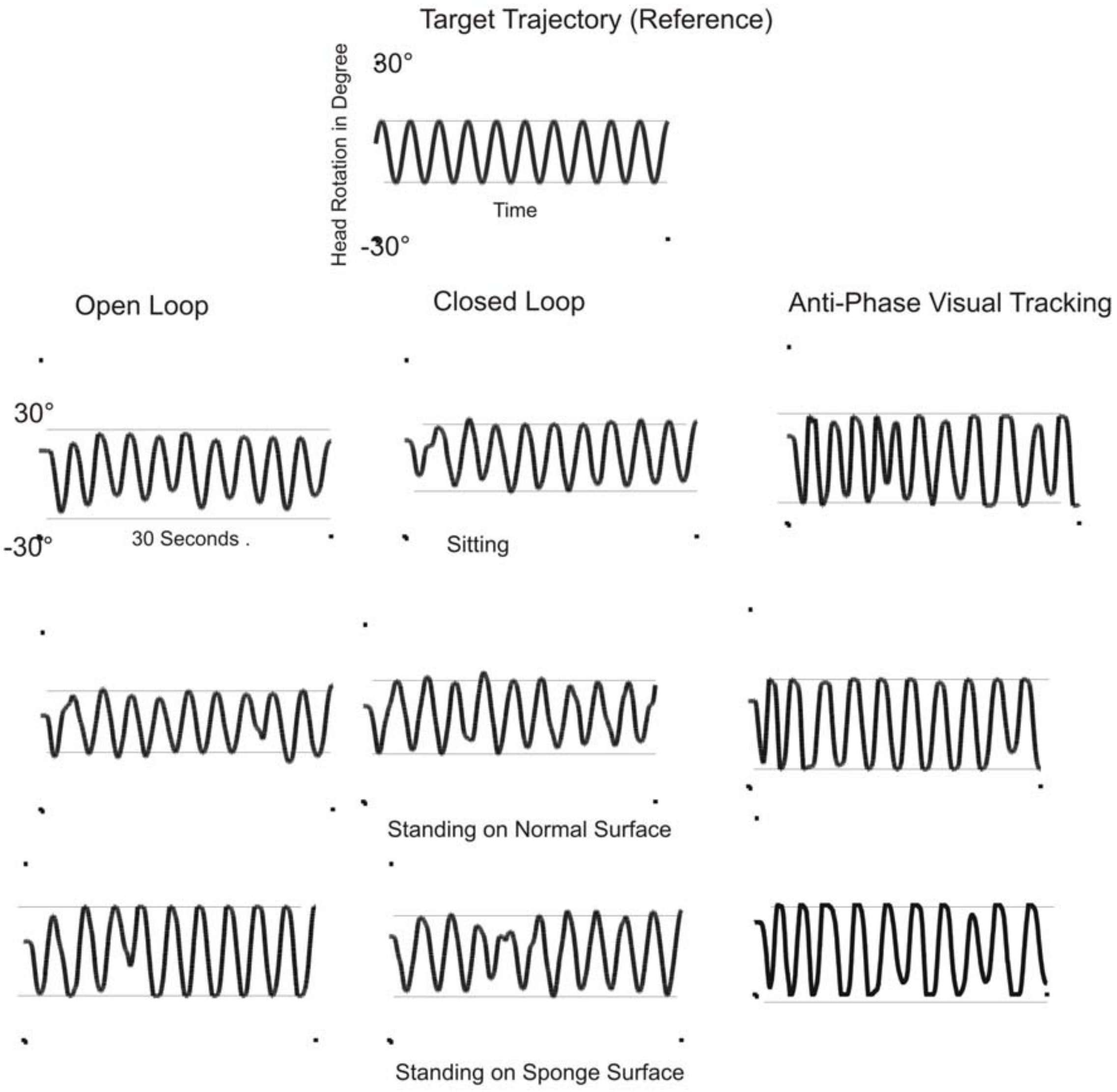
2. *Trunk Motion Measures*:

The trunk (head and arms) represents over half of the total body mass; maintaining control over the motion of the trunk is critical for maintaining stability during standing (Mulavara et al., 2003; Hollands et al 2004; Duysens et al 2008). The following variables were computed form the recorded trunk position signals.

I. Peak-to-peak trunk excursion in rotation (around vertical axis), medial-lateral and anterior-posterior direction:

II. RMS excursions of trunk motion in medial-lateral and anterior-posterior direction and rotation (around vertical axis).

III. Path length of trunk motion in medial-lateral and anterior-posterior direction and rotation (around vertical axis).



Figures7: Presents the trajectory of the target (reference) cursor (top plots) and typical plots of actual head motions during the open loop. Closed loop and anti phase visual tracking conditions in sitting and while standing on normal and sponge surface .

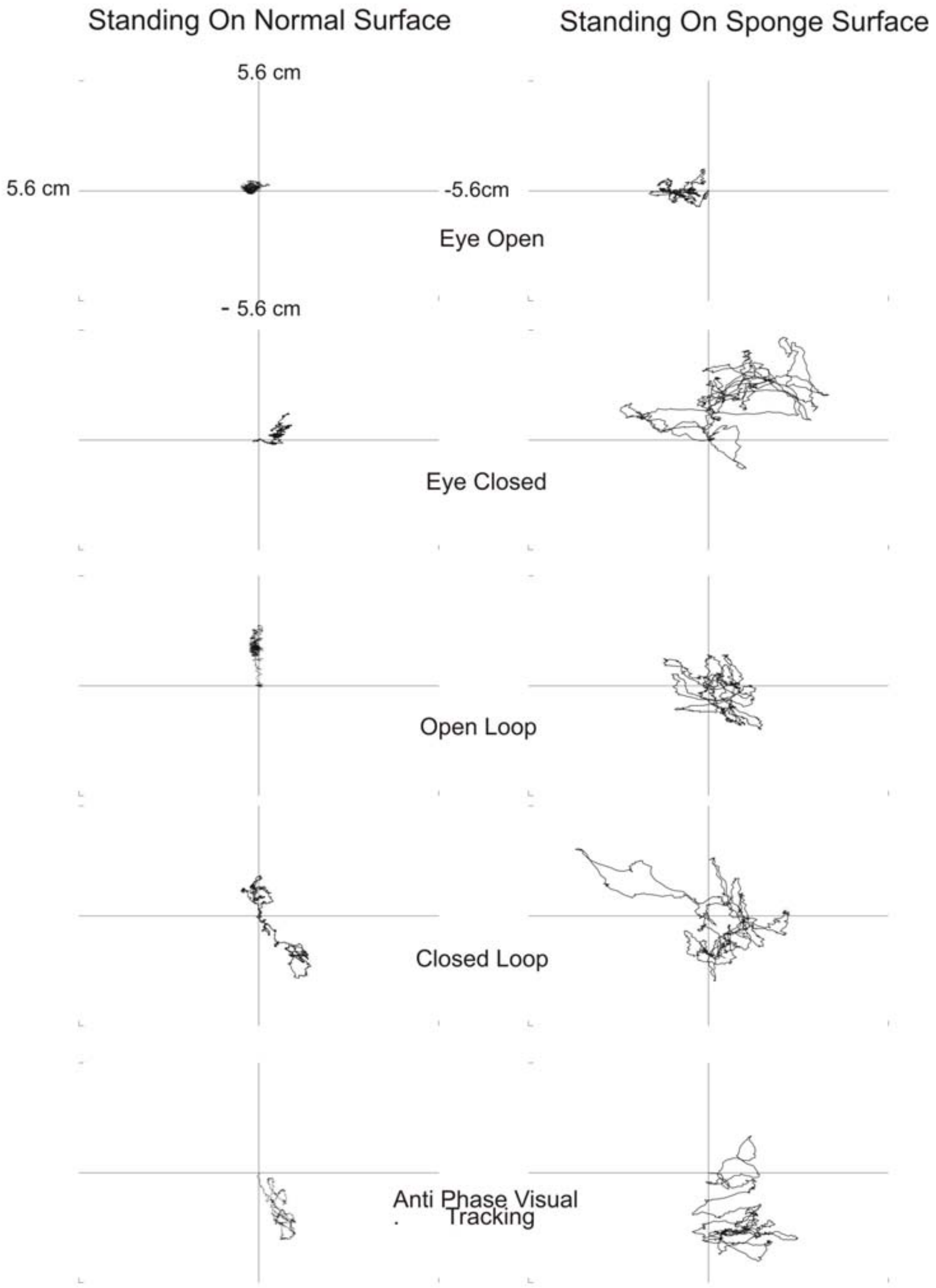


Figure 8: Presents typical plots of COP displacement (30 seconds) during normal and sponge surface standing. The X-axis represent COP movements in Medial-Lateral (ML) directions and Y-axis in Antrior-Posterior (AP) directions.

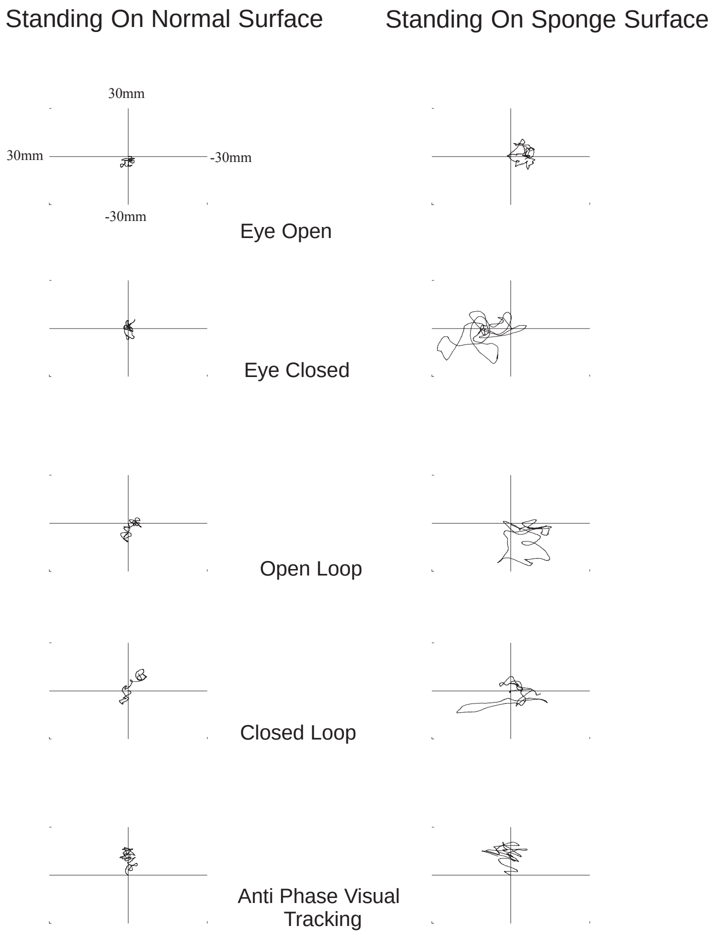


Figure 9: Presents typical plots of raw Trunk displacement (30 seconds) during normal and sponge surface standing. The X-axis represent trunk movements in Medial-Lateral (ML) directions and Y-axis in Anterior- Posterior (AP) directions.

STASTISTICAL ANALYSIS:

Two-way analysis of variance (ANOVA) with repeated measure design was performed to estimate the independent variable effects on the dependent variables, according to the hypotheses. In first hypothesis, effects of physical task demands (2 levels) on stability measures and visual tracking measures were tested. In second hypothesis, effects of visual tracking load (3 levels) on visual tracking performances and stability measures were tested. Whereas third hypothesis was tested for an interaction among both visual tracking task demands and physical task demands. SPSS for windows, version 19, was used to do statistical analysis. The significance level was set at alpha level of 0.5, and a post-hoc Tukey's test with Bonferroni correction was applied, when there was significance. For each repeated measure's ANOVA, we presented the partial Eta Square as a measure of effect size, with higher value representing the strong effect of independent variables.

RESULTS:

1. FIRST OBJECTIVE:

The first objective of this study was to examine the effects of increasing balance demand on stability measures (COP excursions & trunk excursions) and also on visual tracking performances (COD, temporal, and amplitude consistency). Therefore, participants were asked to perform visual tracking task while their balance conditions were challenged, from normal surface standing to standing on a complaint sponge surface.

1.1 Center of pressure (COP) variables:

Typical plots of center of pressure of a single participant are presented in Figure 8. COP traces are offset to a common baseline value of zero for display purposes. During standing on a normal surface and eye open, there is very small COP displacement noticed. In Figure 8, the left panel represents COP excursions while standing on a normal surface, and the right panel shows COP excursions while standing on a sponge surface. It can be clearly seen that standing on a sponge surface substantially increases COP excursion in both directions It is also evident from visual inspection of plots that the visual tracking task demand also influences COP excursions, whether on fixed surface or on sponge surface. There is also an increase in COP excursion during eye-closed condition, especially on the sponge condition.

The ANOVA test showed significant overall differences between fixed and sponge surface COP excursions. The Tukey's multiple comparisons test was used with Bonferroni correction, to find significance within the subject comparison for visual conditions. Therefore, significant p value was adjusted from 0.05 to 0.01 significant level to adjust type I error. The plots of group means and SEMs for mean velocity, peak-to-peak amplitude, and root mean square (RMS) of COP displacement in ML, AP, and rotation are shown in Figures 13 and 14. Statistical results are shown in Table 1. Results showed a significant ($p<0.0001$) effect of physical as well as visual task load on COP variables, peak-to-peak amplitude, path length, and RMS. All three variables of COP are significantly increased from fixed to sponge surface, in both ML and AP directions. Results also showed a significant ($p<0.0001$) interaction effect of physical and visual task demands on COP excursion variables.

Multiple comparison analysis showed mixed significant differences between visual task demands, which were used to challenge COP measures in ML and AP directions. Table 5 & 6 presents, Tukey's multiple comparison results for COP AP and ML RMS excursion. For all of COP excursion measures (path length, peak to peak and RMS) in both directions, only eye-closed condition is significantly differing from eye open, open-loop, closed-loop, and anti-phase tracking task. However, for ML peak-to-peak variable, eye open significantly differ from eye-closed and open-loop tracking task, but no significant difference found in eye-open, closed-loop, and anti-phase tracking. For ML path length and RMS, only eye-closed condition is significantly different from rest.

When we looked for AP path length results showed significant difference in eye-open, eye-closed, and open-loop tracking task and also in between open-loop and anti phase tracking but no significant difference found in between eye open, close loop and anti-phase tracking. On testing of COP-AP peak-to-peak and RMS COP excursions, only eye-close condition significantly differs from eye-open, open-loop, closed-loop, and anti-phase tracking. However, overall results confirmed significant differences in normal and sponge standing while performing visual tracking tasks. These relationships are shown in Figure 13.

1.2 Trunk Sway Variables:

Figure 9 presents the linear trunk displacement in AP and ML directions. In Figure 9 the left panel represents the trunk excursion pattern in normal surface standing, whereas the right panel represents standing on a sponge surface, during eye open, eye closed, open-loop task, closed-loop task and anti-phase tracking task. Trunk excursion during baseline condition, fixed surface and eye open condition, showed very small displacement in AP and ML directions, whereas standing on a sponge surface increases trunk excursion in both directions. Results also showed that in all sponge standing conditions, there were significant displacements in trunk excursion compared to fixed surface standing conditions. These plots show modest displacement in trunk trajectories as balance task demand increases, fixed to sponge surface standing. It is also evident that visual phase tracking tasks influence trunk excursions, whether on a fixed surface or on a sponge surface.

The plots of group means and SEMs for mean velocity, peak-to-peak amplitude, and root mean square (RMS) of trunk displacement in ML, AP, and rotation are shown in Figures 11 and 12. Statistical results are shown in Tables 2 and 3. Results showed significant ($p<0.0001$) effect of physical load on linear ML, AP, and trunk rotation motions. A statistically significant effect ($p<0.0001$) of visual load was also found on linear ML, AP, and trunk rotation movement, except on trunk rotation path length variable. A significant interaction ($p<0.0001$) between physical and visual load is found in all linear ML, AP trunk movement and for trunk rotation path length excursion variable. Results of the statistical analysis are presented in Tables 2 and 3. Analysis of variance showed a significant effect of balance demands, as well as visual task demands on trunk excursions. Tukey's multiple comparisons test with Bonferrone correction was required to compare within subject for visual tasks demands. Table 7 & 8 presents Tukey's multiple comparison results for trunk AP and ML RMS. Results showed for that eye-closed condition is significantly different from other visual conditions for all trunk variables; however, we also found mixed significant results for other trunk variables.

When we compared all visual conditions, for AP path length variable, results showed that eye-open and anti-phase tracking has the same influence while eye-closed, open-loop, and closed-loop is significantly different from both of them. Comparison of open-loop, closed-loop, and anti-phase tracking showed no significant difference from each other for AP path length variable.

For AP peak-to-peak variable, eye open comparison with other conditions showed significant difference from eye closed and open loop tracking task. Whereas open-loop did not show significant difference from closed-loop and anti-phase tracking, significant difference was found from eye-open and eye-closed conditions. Closed-loop and anti-phase tracking comparison to other visual conditions showed significant difference only from eye-closed condition. For AP-RMS variable, only a significant difference was found for eye-closed condition, whereas other comparisons in conditions did not show any significant difference.

Results for ML path length variables also showed mixed significant results. Eye open task comparisons to other conditions showed significant difference to all conditions. Eye closed task comparisons to others showed significant difference from eye open and open loop task, whereas open loop and anti-phase tracking task comparisons to others showed only significant difference from eye open condition. Closed loop task comparison to others showed significant difference from eye open and eye closed condition.

Results for ML peak-to-peak variable showed significant difference between eye open and eye closed, open loop and closed loop condition, in comparison between eye open and other conditions. On comparison of eye-closed condition, significant differences were found from eye open and anti-phase tracking conditions. During open loop and closed loop tasks, comparison with other conditions showed significant difference from eye open condition only. Anti-phase tracking task comparison showed significant difference from eye-closed condition only.

Results revealed no significant effect of any visual task demand on rotation path length variable; all visual demands showed same effects, whereas mixed results were found for rotation peak to peak and rotation RMS variable. For rotation peak-to-peak, eye open comparison with others showed significant difference only from anti phase tracking task. Eye closed condition comparison with others showed significant difference from open loop, closed loop and anti-phase tracking task. Open loop comparison with others showed that this only significantly differs from eye close condition. Close loop differs significantly from eye closed and anti-phase tracking. Anti-phase tracking comparison showed significant difference from eye open, eye closed and closed loop tasks.

Trunk rotation RMS results also showed mixed significant results. Eye open comparison with others showed only significant difference from closed loop task. Whereas eyes closed condition comparison showed only significant difference from anti phase tracking. Open loop task comparison with others did not show any significant difference from others. However close loop task comparison showed significant difference from anti phase tracking and eye open condition. Anti-phase task demand is compared with others and found significant difference from closed loop and eye closed condition.

These mixed results might be due to the task performance requirement, which included head rotation that further influences trunk movements.

1.3 Visual tracking performance:

Plots of group means and standard error means (SEMs) for Coefficient of Determination (COD), temporal accuracy, and amplitude consistency between baseline condition (visuo-tracking task while sitting) and during condition (standing at various surfaces) are presented in Figure 10 and statistical results presented in table 1.

Results did not show any significant effect of increasing balance demands on visual tracking performances.

2. SECOND OBJECTIVE:

Second object of the study was to examine the effects of increasing visual tracking demands on visual tracking performances as well as on stability measures. Visual tracking tasks included open-loop tracking, closed-loop tracking, and anti-phase tracking. All three tasks were different in foveation requirements. Physical tasks included sitting, standing on normal surface and standing on sponge surface.

2.1 Visual tracing performance:

Typical plot of movement trajectory (cursor slaved to head rotation) of a single subject during sitting and standing on various surfaces while performing simple to most difficult visual tracking tasks, are shown in Figure 7. The reference trajectory (trajectory of the moving cursor) shows a regular sinusoidal pattern of trajectory. This shows that the reference cursor has moved from one edge to another edge of the computer screen with constant speed and without any interruption. However, there are some irregular movements and deviations in amplitude consistency. It can be seen that the physical load affects the amplitude consistency. Figure 7 also presents actual head rotation trajectories in sitting and standing on both surfaces. During sitting and standing on normal surfaces, there are few deviations in amplitude for cycle maxima and minima. Deviations in amplitude are much greater and more frequent during standing on the sponge. Movement trajectory during open-loop tracking exhibits a regular and smooth sinusoidal movement pattern similar to reference trajectory. The head motion trajectories become more irregular and distorted during the closed-loop tracking condition.

Plots of group means and standard error means (SEMs) for Coefficient of Determination (COD), temporal accuracy, and amplitude consistency between baseline condition (visuo-spatial task while sitting) and dual-task condition (standing at various surfaces) are presented in Figure 10. Results showed significant influence of visual-tracking task load on COD ($p< 0.03$), amplitude consistency ($p< 0.0001$), and temporal accuracy ($p<0.001$), but there is no significant effect found for physical task demand and there is no interaction effect found between both, visual task and physical task demand, on visuo-spatial dependent variable. Results of the statistical analysis are presented in Table 4.

Results showed that amplitude consistency and temporal accuracy was reduced for closed loop visual conditions compared to open loop visual condition, but there is no significant effect found in both. Figure 10 shows visual performance results.

2.2 Stability measures (COP & Trunk variables):

Stability measures included COP and trunk excursions (Path length, peak to peak and RMS). The plots of group means and SEMs for mean velocity, peak-to-peak amplitude, and root mean square (RMS) of COP and trunk displacement in ML, AP, and trunk rotation are shown in Figures 11,12,13 and 14. Statistical results are shown in Table 2,3 and 4. These tables showed significant effect ($p < 0.0001$) of visual load on COP and trunk measures (path length, peak to peak and RMS), therefore Tukey's multi comparison test with Bonferroni correction was used to find which visual load task showed significant effect on stability measures. Results showed that only eye closed condition is significantly ($p<0.0001$) influencing on stability measures and none of visual tracking task showed any significant effect on stability measures.

Table 1: Effect of physical load and visual load on Center of pressure (COP).

Variable	Physical Load		Visual Load		Interaction	
	ML	AP	ML	AP	ML	AP
COP-Path Length	p<0.0001 F=97.9 (1,19) σ = 0.57	p<0.0001 F=230.0(1,19) σ = 0.82	p<0.0001 F=15.1(4,16) σ = 0.45	p<0.0001 F=63.8(4,16) σ = 0.83	p<0.0001 F=6.2(4,16) σ = 0.25	p<0.0001 F=26.7(4, 16) σ = 0.68
COP-Peak to Peak	p<0.0001 F=157.4(1,19) σ = 0.71	p<0.0001 F=217.0(1,19) σ =0.81	p<0.0001 F=929.2(4,16) σ =0.55	p<0.0001 F=59.9(4,16) σ =0.82	p<0.0001 F=12.2(4,16) σ =0.44	p<0.0001 F=39.2(4, 16) σ =0.75
COP-RMS	p<0.0001 F=97.9(1,19) σ = 0.57	p<0.0001 F=59.9(1,19) σ =0.50	p<0.0001 F=15.1(4,16) σ =0.45	p<0.0001 F=11.7(4,16) σ =0.44	p<0.0001 F=6.2(4,16) σ =0.25	p<0.0001 F=12.8(4, 16) σ =0.46

COP = Center of Pressure, RMS = Root Mean Square, σ = Effect size,AP = Anterio-Posterior, ML = Medio- Lateral

Table 2: Effect of physical load and visual load on Trunk Motion.

Variable	Physical Load		Visual Load		Interaction	
	ML	AP	ML	AP	ML	AP
Path Length	$p<0.0001$ $F=285.9(1,19)$ $\sigma = 0.81$	$p<0.0001$ $F=206.1(1,19)$ $\sigma = 0.77$	$p<0.0001$ $F=9.6(4,16)$ $\sigma = 0.36$	$p<0.0001$ $F=18.8(4,16)$ $\sigma = 0.55$	$p<0.0001$ $F=34.1(4,16)$ $\sigma = 0.67$	$p<0.0001$ $F=26.6(4,16)$ $\sigma = 0.64$
Peak to Peak	$p<0.0001$ $F=174.1(1,19)$ $\sigma = 0.737$	$p<0.0001$ $F=145.9(1,19)$ $\sigma = 0.723$	$p<0.0001$ $F=9.3(4,16)$ $\sigma = 0.375$	$p<0.0001$ $F=28.1(4,16)$ $\sigma = 0.668$	$p<0.0001$ $F=12.2(4,16)$ $\sigma = 0.385$	$p<0.0001$ $F=15.9(4,16)$ $\sigma = 0.533$
RMS (Root mean squared)	$p<0.0001$ $F=133.4(1,19)$ $\sigma = 0.66$	$p<0.0001$ $F=88.4(1,19)$ $\sigma = 0.61$	$p<0.001$ $F=5.3(4,16)$ $\sigma = 0.24$	$p<0.0001$ $F=9.2(4,16)$ $\sigma = 0.40$	$p<0.0001$ $F=8.4(4,16)$ $\sigma = 0.34$	$p<0.0001$ $F=18.6(4,16)$ $\sigma = 0.57$

COP = Center of Pressure, RMS = Root Mean Square, σ = Effect size,
AP = Anterio- Posterior, ML = Medio- Lateral

Table 3: Effect of physical load and visual load on Trunk Rotation.

Variable	Physical Load	Visual Load	Interaction
Path Length	$p<0.0001$ F=41.2(1,19), $\sigma = 0.34$	N S $\sigma = 0.07$	$p<0.002$ F=4.7(4,16), $\sigma = 0.19$
Peak to Peak	$p<0.0001$ F=36.9(1,19) , $\sigma = 0.38$	$p<0.0001$ F=10.1(4,16), $\sigma = 0.41$	N S $\sigma = 0.10$
RMS (Root mean squared)	$p<0.016$ F=6.08(1,19) $\sigma = 0.08$	$p<0.0001$ F=6.05(4,16) $\sigma = 0.26$	N S $\sigma = 0.11$

COP = Center of Pressure, RMS = Root Mean Square, σ = Effect size, NS = Not Significant, AP = Anterio- Posterior, ML = Medio- Lateral

Table 4: Effect of physical load and visual load on visual task performance

Variable	Visual Load	Physical load	Interaction
COD	$p < 0.03$ $F = 3.4$ (2,18) $\sigma = 0.32$	NS $\sigma = 0.02$	NS $\sigma = 0.03$
Temporal Accuracy	$p < 0.001$ $F = 14.16$ (2,18) $\sigma = 0.32$	NS …(need to check) $\sigma = 0.$	NS $\sigma = 0.32$
Amplitude Consistency	$p < 0.0001$ $F = 24.204$ (2,18) $\sigma = 0.51$	NS $\sigma = 0.$	NS $\sigma = 0.02$

COD = Coefficient of determination, σ = Effect size, NS = Not Significant, AP = Anterio- Posterior, ML = Medio- Lateral

3. THIRD OBJECTIVE:

Third object was to examine the effects of interactions, in between balance demands and visual tracking demands, on trunk sway, COP excursion, and visual tracking performance. The interactions of balance demands and visual tracking conditions on trunk sway, COP excursion, and head tracking performance were examined using two-way repeated measure analysis of variance (ANOVA). Balance demands were included standing on a fixed and compliant sponge surfaces and visual tracking conditions included open-loop tracking, closed-loop tracking, and anti-phase tracking, with respect to head movements. Table one shows that no interaction found for visual tracking performance which mean increasing balance demand and increasing visual tracking demands did not affect COD, temporal accuracy and amplitude consistency. However, significant ($p<0.0001$) interactions were found for most of stability measures (COP and trunk excursions) and table 2,3 and 4 presents statistical results. The plots of group means and SEMs for mean velocity, peak-to-peak amplitude, and root mean square (RMS) of COP and trunk displacement in ML, AP, and trunk rotation are shown in Figures 11,12,13 and 14.

Visual Variables

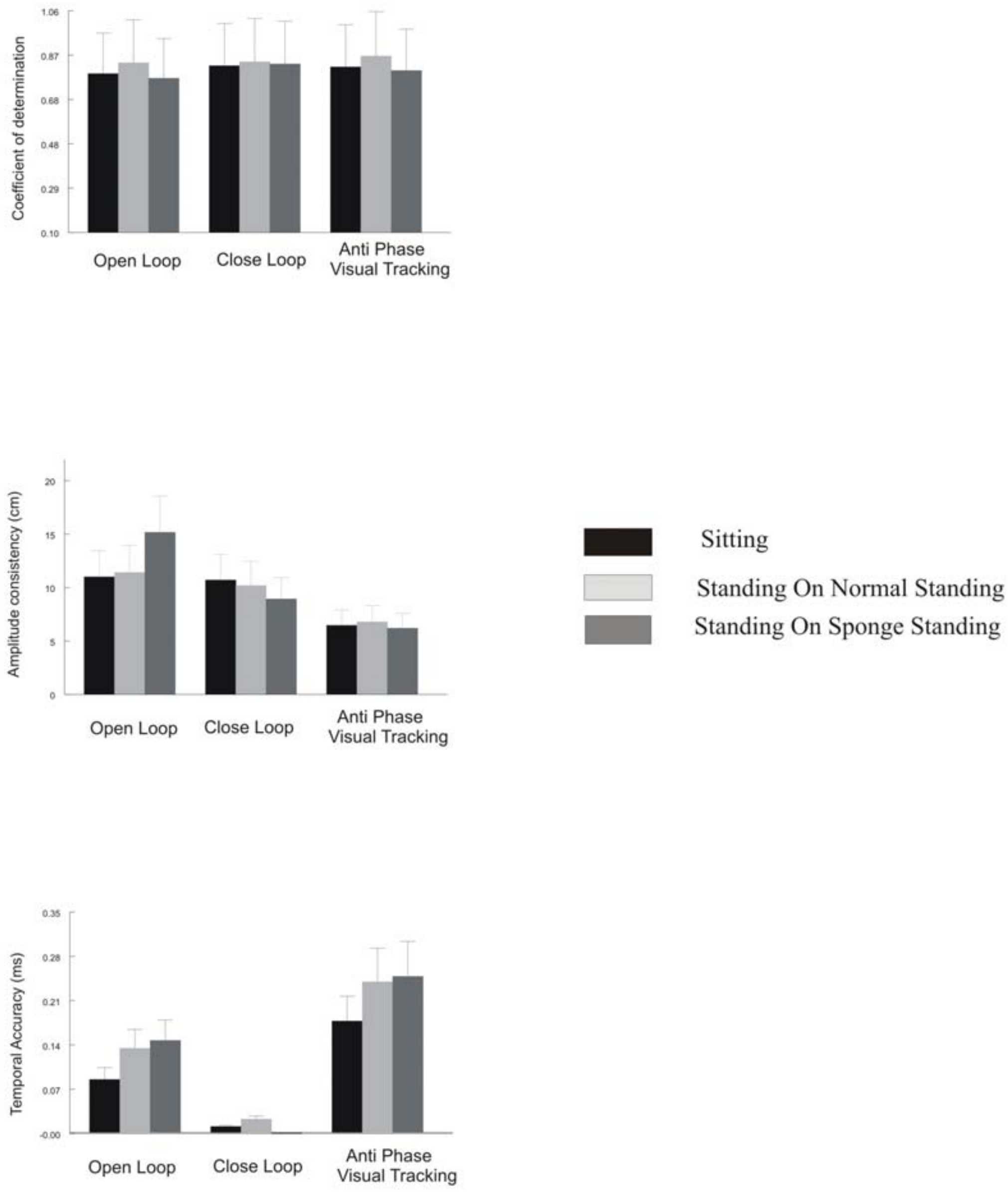


Figure 10 Presents group means and SEM of Coefficient of determination(COD), Amplitude consistency and Temporal accuracy are presented in sitting, normal and sponge standing.

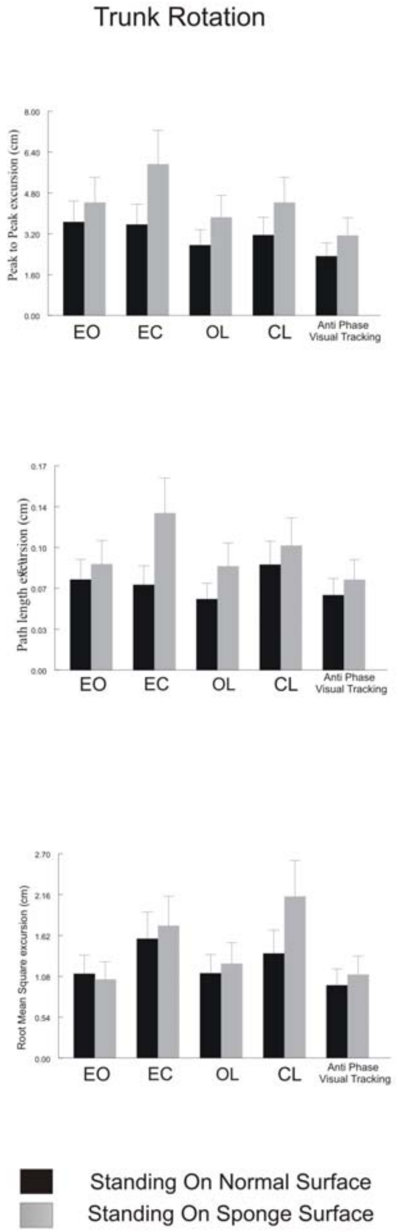


Figure 12 presents the group means and SEM of peak to peak amplitude, path length and root mean square of trunk rotation during normal and sponge surface standing with Eyes Open (EO); Eyes Closed (EC); Open Loop (OL); Closed Loop (CL) and anti phase visual tracking.

AP COP Excursion

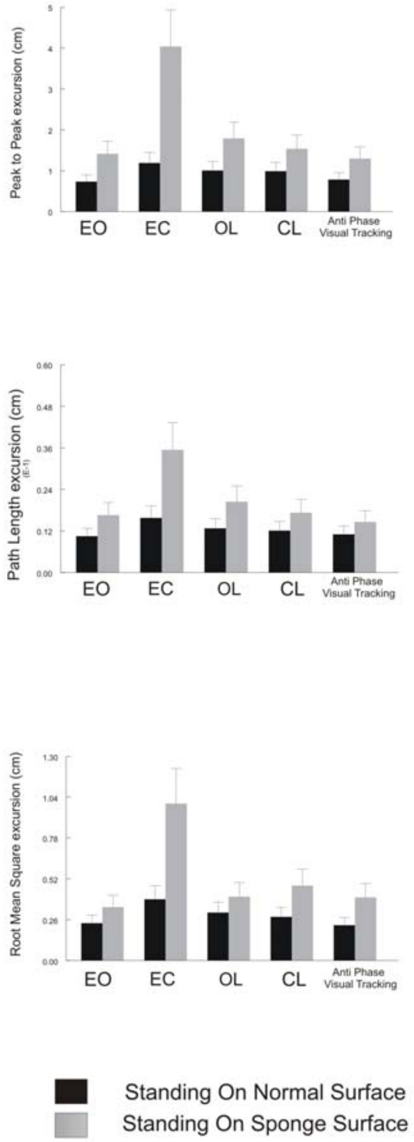


Figure 13 presents the group means and SEM of peak to peak amplitude, path length and root mean square of linear AP COP excursion during normal and sponge surface standing with Eyes Open (EO); Eyes Closed (EC); Open Loop (OL); Closed Loop (CL) and anti phase visual tracking.

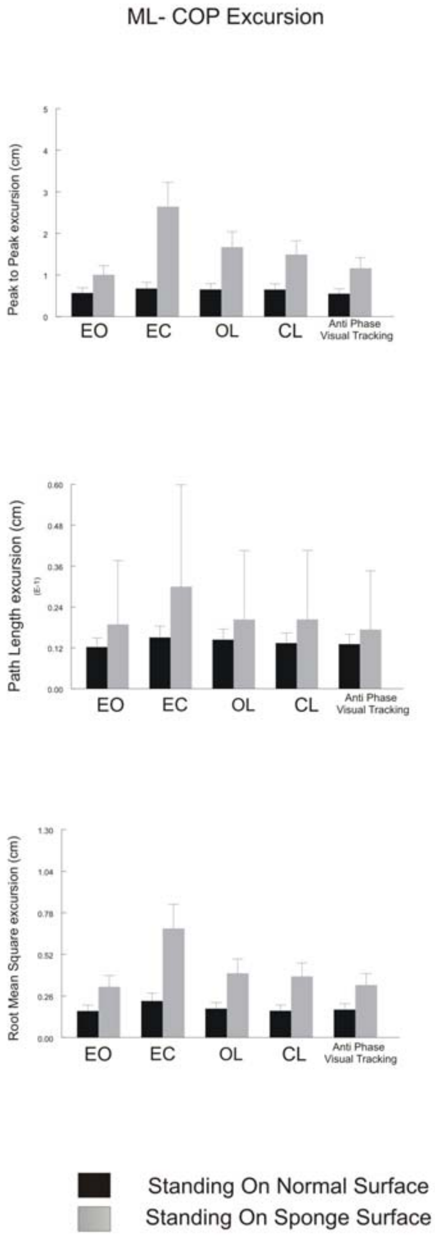


Figure 14 presents the group means and SEM of peak to peak amplitude, path length and root mean square of linear ML COP excursion during normal and sponge surface standing with Eyes Open (EO); Eyes Closed (EC); Open Loop (OL); Closed Loop (CL) and anti phase visual tracking.

Table 5: Tukey's test (Multiple comparisons) for COP-ML RMS excursion.

Visual Task (A)	Visual Task (B)	Standard Error	Difference
Eye Open	Eye Close	.03440	Significant
	Open Loop	.03316	N.S
	Close Loop	.03613	N.S
	Anti Phase Tracking	.03394	N.S
Eye Close	Eye Open	.03440	Significant
	Open Loop	.03126	Significant
	Close Loop	.03440	Significant
	Anti Phase Tracking	.03209	Significant
Open Loop	Eye Open	.03316	N.S
	Eye Close	.03126	Significant
	Close Loop	.03316	N.S
	Anti Phase Tracking	.03075	N.S
Close Loop	Eye Open	.03613	N.S
	Eye Close	.03440	Significant
	Open Loop	.03316	N.S
	Anti Phase Tracking	.03394	N.S
Anti Phase Tracking	Eye Open	.03394	N.S
	Eye Close	.03209	Significant
	Open Loop	.03075	N.S
	Close Loop	.03394	N.S

COP= center of pressure, ML= Medio –Lateral, RMS= Root Mean Square, N.S = Not Significant

Table 6: Tukey's test (Multiple comparisons) for COP-AP RMS excursion.

Visual Task (A)	Visual Task (B)	Standard Error	Difference
Eye Open	Eye Close	.059285	Significant
	Open Loop	.064943	N.S
	Close Loop	.059285	N.S
	Anti Phase Tracking	.061706	N.S
Eye Close	Eye Open	.059285	Significant
	Open Loop	.064943	Significant
	Close Loop	.059285	Significant
	Anti Phase Tracking	.061706	Significant
Open Loop	Eye Open	.064943	N.S
	Eye Close	.064943	Significant
	Close Loop	.064943	N.S
	Anti Phase Tracking	.067161	N.S
Close Loop	Eye Open	.059285	N.S
	Eye Close	.059285	Significant
	Open Loop	.064943	N.S
	Anti Phase Tracking	.061706	N.S
Anti Phase Tracking	Eye Open	.061706	N.S
	Eye Close	.061706	Significant
	Open Loop	.067161	N.S
	Close Loop	.061706	N.S

COP= center of pressure, AP= Anterio- Posterior , RMS= Root Mean Square, N.S = Not Significant

Table 7: Tukey’s test (Multiple comparisons) for Trunk- AP RMS excursion

Visual Task (A)	Visual Task (B)	Standard Error	Difference
Eye Open	Eye Close	1.539754	Significant
	Open Loop	1.504601	N.S
	Close Loop	1.580906	Significant
	Anti Phase Tracking	1.447638	N.S
Eye Close	Eye Open	1.539754	Significant
	Open Loop	1.568883	Significant
	Close Loop	1.642204	Significant
	Anti Phase Tracking	1.514340	Significant
Open Loop	Eye Open	1.504601	N.S
	Eye Close	1.568883	Significant
	Close Loop	1.609290	N.S
	Anti Phase Tracking	1.478583	N.S
Close Loop	Eye Open	1.580906	N.S
	Eye Close	1.642204	Significant
	Open Loop	1.609290	N.S
	Anti Phase Tracking	1.556164	N.S
Anti Phase Tracking	Eye Open	1.447638	N.S
	Eye Close	1.514340	Significant
	Open Loop	1.478583	N.S
	Close Loop	1.556164	N.S

AP = Anterio- Posterior, RMS= Root Mean Square,   N.S = Not Significant

Table 8: Tukey's test (Multiple comparisons) for Trunk-ML RMS excursion

Visual Task (A)	Visual Task (B)	Standard Error	Difference
Eye Open	Eye Close	2.88204	Significant
	Open Loop	2.78431	Significant
	Close Loop	2.88204	Significant
	Anti Phase Tracking	2.88204	N.S
Eye Close	Eye Open	2.88204	Significant
	Open Loop	2.78431	N.S
	Close Loop	2.88204	N.S
	Anti Phase Tracking	2.88204	Significant
Open Loop	Eye Open	2.78431	Significant
	Eye Close	2.78431	N.S
	Close Loop	2.78431	N.S
	Anti Phase Tracking	2.78431	N.S
Close Loop	Eye Open	2.88204	Significant
	Eye Close	2.88204	N.S
	Open Loop	2.78431	N.S
	Anti Phase Tracking	2.88204	N.S
Anti Phase Tracking	Eye Open	2.88204	N.S
	Eye Close	2.88204	Significant
	Open Loop	2.78431	N.S
	Close Loop	2.88204	N.S

ML= Medio –Lateral, RMS= Root Mean Square, N.S = Not Significant

DISCUSSION:

The aim of this study is to evaluate how visual- tracking tasks, which require foveation along with head movements, influence stability during standing on various surfaces or vice versa. To evaluate that three objectives and hypothesis were developed for the study.

The main finding of this study revealed that the increasing balance demands significantly affect stability and also increasing visual tracking demands affect visual tracking performances. Although there were no significant effects of neither increasing visual tracking tasks demand on stability measures nor increasing balance demands on visual tracking performances. However, results showed a significant interaction effect between balance conditions demands and visual tracking demands.

1. First objective : Effects of increasing balance demands on stability/balance measure and on visual spatial tracking performance:

Our study has examined the effect of increased balance demands on balance/stability measures, COP, and trunk measures. For each outcome variable of interest, we reported peak-to-peak excursion, path length, and RMS in ML-AP directions of trunk and COP movement trajectories and for visual tracking, COP, amplitude consistency, and temporal accuracy while performing task while standing.

1.1 Effects on COP measures:

This study reported an increment in peak-to-peak amplitude, path length, and RMS in both ML in AP directions as standing surface changed from normal to sponge. These results are similar to the studies that have been done to find surface influences on

COP excursions (Lord & Ward, 1994; Melzer et al., 2004; Jeka et al., 2004; Creath et al., 2005; Rosengren et al., 2007; Desai et al., 2010; D' Hondt et al., 2011).

Our findings are similar to those of Lord and Ward (1994), which also denoted that surface properties increases body sway movement. For their study, 414 community-dwelling women participated (over 65 years) with 136 younger women (age 20-65 years). This study has been done to study age-associated changes in sensori-motor function and balance. Participants were asked to perform 9 different tasks to challenge various sensori-motor systems (proprioception, vibration, touch, vestibular, and visual senses), and 5 composite tests included a test of reaction time and tests of body sway on firm and compliant (foam rubber) surfaces. A swaymeter was used to record displacement in body sway. Their results showed significant increment in sway path length when participants stood on a compliant surface compared to a firm surface. This increment was noticed for both groups, younger and community-dwelling women.

Results were consistent with Shumway-Cook et al.'s (1997) study, where they asked their participants to stand on firm and compliant surfaces for examining postural stability. This study has been done to investigate the effects of cognitive load on stability in various age groups. Sixty participants were included for young, older adult and older adult with fall history group (20 each). Center of pressure (COP) measures were used to quantify postural stability among groups, and force plate was used to record COP displacement during standing. Results showed similar patterns of COP displacement on compliant surface standing in all three groups. Results showed significantly increased COP movements on compliant surface compared to firm surface, which further showed more instability among participants. Another study done by Melzer et al. (2004) to find biomechanical measures for fallers in the elderly population also found similar results of increasing COP path length when participants were asked to stand on a foam surface with narrow base of support compared to a fixed surface. Desai et al. (2010) also observed significant increments in AP and ML-COP peak-to-peak excursion along with path length on a sponge surface compared to fixed surface.

All these discussed studies have revealed that all COP excursions were significantly increased on compliant surface compared to their fixed floor conditions, hence the property of supporting surface does influence one's balance without dual task involvement.

1.2 Effects on Trunk measures:

The trunk represents 50% of the body's total mass; therefore, the motion of the trunk is critical for maintaining the stability of the entire body (Winter et al., 1990). The control of the position and motion of trunk (head and arms) relative to base of support is a main contributor to overall stability during standing because most falls occur when a person loses control of the upper body. We hypothesized that an increasing balance demand would result in an increment in trunk excursions also. Gill et al. (2001), Allum et al. (2001), and Blackburn et al. (2003) also found that an altered support surface increases the trunk excursions in AP and ML directions that further influence stability during standing.

Gill et al. (2001) has studied effects of age on trunk sway and postural stability during balance tests. The study included 147 participants, for three different age groups, young (15-25), middle (45-55) and elderly (65-75). Participants were asked to stand with eyes open on fixed and foam surfaces, and trunk movements were recorded by two angular-velocity transducers mounted in a belt at the lumbar region. Their results have showed a significantly increased trunk sway in AP and ML direction on sponge surface compared to fixed surface. They also revealed that this increment is more prominent in the elderly population compared to middle and younger populations.

In studies to find the sensitivity of trunk sway during clinical balance test, Allum et al. (2001) included normal health adults and two different groups of vestibular deficit participants with unilateral peripheral and unilateral cerebellar-pontine angle tumor disorder. Their study has also found the similar result of increased trunk sway when participants performed standing on a sponge condition compared to normal surface standing. It also denoted that trunk sway was prominently higher and provided reliable and quantitatively distinguished information about balance deficit from healthy controls. On contrary, Blackburn et al. (2003) found no significant difference in trunk sway in fixed surface condition and sponge surface condition. Although the study found only increased trunk sway in AP and ML direction for sponge surface condition compared to fixed surface condition. This study has investigated the role of hip and trunk motions during balance control mechanism. It has revealed that trunk motion plays a major role in balance control mechanism along and similar to hip motions.

1.3 Effect on visual tracking performance:

There is limited research that examines the effect of standing surface condition on visual tracking performance with increased attention requirements. We hypothesized that increased balance demand would decreased the visual tracking performance among participants. In contrast, our findings suggested that increasing physical load or balance demand did not affect any of visual performance variables, COD, temporal accuracy, and amplitude consistency. Some studies have investigated increasing physical load influence of visuo-spatial performance, reaction time based on verbal cues rather than visuo-spatial tracking performance. Yu et al (2010) have done a study to find out how increase-balancing demand influences visuo-spatial performance among healthy adults. Their visuo-spatial task involved identification of presented stimuli on a computer screen, easy or hard. Response to the visual stimuli was recorded to denote visual performance. It revealed that as balance demand increased, it significantly influenced visual performances. These results are contrary to our findings because our study did not reveal any influence on visual tracking performances. This could be possible because we have used a different approach of visual tracking than used by Yu et al.(2010). In our study, participants had to track a moving dot on a computer screen, whereas visuo-spatial task in Yu et al.(2010) study did not require any head-eye coordination.

Ludovic et al. (1998) as found a similar result while they were looking at interaction between task demands and influence of support surface while standing. The twelve participants were asked to perform a visual tracking task in fore-aft direction, and an object was presented on a front screen through a head projector. Dependent variables for head tracking performance included peak-to-peak amplitude of head movement, cross-correlation efficient between target and head movement, and phase lag between target and head movement along with hip ankle relative phase. Full body stability was computed from Ariel video motion analysis system. Their results significantly showed surface influence on tracking performance as well as on body sway. Results showed no difference for peak-to-peak amplitude, but there were positive phase lag noticed compared to fixed surface. It also concluded that there was an interaction effect between task demand and surface properties. In another study, Lajoie et al. (1993) also found that increasing balance demand decreases the attention task performance. They used reaction time (RT) to represent attention toward task performance; attention task was an auditory stimulus and verbal response required to get RT.

Cantin et al (2007) findings are opposite to Lajoie et al (1993) and their results showed no effect of balance demands on stroop word (visuo- spatial task) task performance in health young adults, although traumatic brain injury participants showed effect of balance demand on visuo-spatial task performances. Our findings also showed no effect of increasing balance demands on visual tracking performances, which also required attention and accuracy to perform the visual tracking task.

2. Second objective: Effects of increasing visual tracking task demand

Our study has examined the effect of increased visual tracking demands on visual tracking parameters (COD, Temporal accuracy and amplitude consistency), balance/stability measures, COP, and trunk measures while performing task while standing.

2.1 Visual task performances:

Independent of balance load, the second objective of this study was to evaluate effect of vision and increasing visual tracking task demand on stability/balance measure and visual tracking performances. In the present study, we also found that visions play a significant role in balance control mechanism in simple tasks. Similar results were found in other research (Edwards, 1946; Lord & Ward, 1994; Kuo et al., 1998; Peterka, 2002; Jeka et al., 2003; Creath et al., 2005; Rosengren et al., 2007; Desai et al., 2010, D'Hondt et al., 2011). The present study has also revealed that an increasing complexity of visual tracking task demand significantly influenced visual performance; however, there is no significant influence on COP and trunk excursion parameters.

There are many studies (Lajoie, Teasdale, Brad & Fleury, 1993; Van Iersel Kessels, Bloem, Verbeek & Rikkert, 2008; Dingwell, Rodd, Troy & Grabiner, 2008; Hausdorff, Schweiger, Herman & Seligmann 2008), which have looked on performances based on cognitive task, visual-spatial attention tasks and memory tasks but none of study have looked on performances when visual tracking task demand increases. In our study, visual tasks were different in visual attention demands. Open loop task did not require much foveation and feedback to track whereas closed loop task required much more fovation towards slaved paddle and a feedback process to overlap on moving target. Anti-phase tracking required more peripheral vision to perform the task because participants had to move their head in opposite direction to the moving target on screen.

But there are studies, have shown reduction in performance when complexity of cognitive or visuo-spatial tasks increase. Study by Cantin et al (2007) have also found that complex visual task took longer to complete compare to simple visual task. Study used two Stroop tasks. Simple task was to name the color of presented bar and complex task was to name the color of presented words and words were presented either in same or different color than their lexical name. Results showed that complexity of visual task influenced participant's performance even in sitting condition.

2.2 effects on stability measures (COP and Trunk variables):

Our results reveled that increasing visual tracking load, solely, did not affect stability measures and only eye closed condition increased COP and trunk displacement. Our finding in eye closed condition is similar to other studies which have shown that eye closed condition increases body sway (Kuo et. al., 1998; Blackburn et al., 2003; Jeka et al., 2004; Varncken et al., 2005; Rosengren et al., 2007). Human upright stance is achieved by coordination of visual, vestibular and proprioceptive sensory system (Blackburn et al., 2003; Jeka et al., 2004; Rosengren et al., 2007). Thus, during eye closed condition the postural control system must adjust to maintain stance in a provided environmental conditions (Peterka et al. 2002, Sozzi, Monti, Marco De Nunzio, Do, Schieppati, 2010) therefore increased in body sway. The presence or absence of vision changes the strategy employed for the maintenance of postural stability.

Kuo et al (1998) and Sozzi et al. (2010) also found similar result when they compered eye open and eye closed condition on normal surface. Healthy participants (young adult) were asked to perform eye open and eye closed tasks during quite standing on floor. There results showed significant increment in body sway during eye-closed condition in compare to eye open on normal floor. Rosengren et al. (2006) findings also supported our finding of increasing body sway in eye-closed condition. Their study included health older women and asked to perform eye open and eye closed task with quite standing on fixed surface. Their results showed better performance with eye open condition.

None of study has looked increasing visual tracking demand effect on stability during standing but Strupp et al (2003) study has looked only on smooth pursuit task effect on stability. Strupp et al. (2003) have found contrary results to our findings when participants were asked to performed smooth pursuit task. Their findings have shown increment in COP sway during smooth pursuit task in compare to space fixed target task. However, study did not discuss about required head movement to perform smooth pursuit task because only head movement can also affect stability during standing (Mulavara & Bloomberg 2002; Hollands, Ziavra & Bronstein 2004, Cinell, Ptla & Stuart, 2007; Duysens et al., 2008, Bonnet et al., 2010). Whereas in our study, participant required less head movements in compare to other discussed studies and therefore did not find any significant effect of visual tracking task on stability measuers.

3. Third objective: Interaction between visual tracking task demand and balance demand:

The third aim of this study was to examine the interaction effect of increasing visual tracking task demand and standing balance demand on COP excursions and trunk excursions, as well as on visual tracking task performance. Our findings did not show any significant interaction effect on visual tracking task performances. However, significant interactions were found for all COP and trunk excursion including peak-to-peak, path length, and RMS.

3.1 Effect on COP measures:

Studies have revealed that whenever balance requirement increases, it reflects on increments in COP excursion, peak-to-peak, path length, and RMS (Melzer et al. 2004, Jeka et al., 2004, Creath et al., 2005, Rosengren et al., 2006, Desai et al., 2010, D'Hondt et al., 2010). The present study has also revealed the consistency of result and interaction effect on COP peak-to-peak excursion, path length, and RMS. Our findings have showed that increasing demand of visual tracking tasks alone did not influence COP measures, but in dual task conditions, it significantly increased the COP excursions in all peak-to-peak, path length, and RMS which further affect balance measure.

To find an interaction dual task paradigm was used, studies have used various tasks involving memory, attention, eye movements, etc. Maylor et al. (2001) found that postural sway variability was increased in AP and ML direction while performing cognitive task in comparison to no cognitive task (single task). This study has included younger and older (20 to 70 year) participants, and results revealed that older participants showed significantly greater sway variability in both AP and ML direction compared to younger participants. Although in the present study we have used visual tracking task whereas Maylor et al. (2001) used memory task, results showed a consistency of increasing COP variability but no influence of position (sitting vs standing) on cognitive performance. Results are also similar for interaction between cognitive task and COP variability.

Similar results were found in Hunter et al.'s study (2001) where younger participants displayed significantly greater COP variability for a task that involved eye movements than no-eye movement task. In no-eye movement task, participants had to stand stationary and look on a visual target presented directly in front of them, whereas the eye movement task involved focusing on a visual target presented on various locations of computer screen. The COP variability was only observed in ML direction but not in AP direction due to their task protocol where participants were asked to stand in Tandem Romberg stance (heel to toe). However, the stability of standing depends on the base of support; normal standing shows greater instability in AP direction whereas Tandem stances show in ML direction (O'Connor et al., 2009).

Doumas et al. (2008) has found contrary result of no dual task effect on balance/stability in younger adults; however, older adults showed a significant increment in COP variability in AP and ML direction. In this study, 18 younger adults and 18 older adults participated. During single task, for balance performance, participants were asked to speak the presented number on screen while standing on fixed surface. On the other hand, dual task required speaking 2 back digits from the presented number on the computer screen. They also suggested that during increased balance demand in dual task would not affect much on COP variability because of periodization of stability over secondary task performance (cognitive).

As we noticed in this research, some suggested increasing COP excursion in dual task performance while others suggested reduction in COP excursion compared to single task. Therefore, postural stability can be affected by cognitive activity in complex ways, depending on the age of participants and the type of cognitive task used in dual task (Maylor et al., 2001; Beauchet et al., 2005).

3.2 Effect on Trunk motion:

In the present study, we found a significant increase in path length, peak-to-peak excursion, and RMS of trunk motion in AP and ML direction and for rotation in between control condition (standing with eyes open) and standing and preforming visual tracking task. Trunk excursions are significantly higher for eye-closed condition whether on fixed surface or on sponge surface in their group. There is a significant increment in other dual task conditions where participants performed concurrent open-loop, closed-loop or anti-visual tracking tasks with physical task. It is evidently revealed that trunk excursion increased in dual task, visual tracking with physical task, compared to single task, eye open standing, performance. Our findings showed similar results as Haggerty et al.'s (2012) study. This study was done to find biofeedback effect on trunk movements during dual tasking in community dwelling populations. Ten community dwelling older adults (68 to 80 years) participated, and they were asked to perform response time based secondary task. Single task required standing still on a fixed surface, and DT required responses to an auditory stimuli in two ways, first speaking high or low tone; in other one, participant had to press a button to respond to high or low tone. Trunk movements recorded by an inertial measurement unit (Xsens tech.), which was placed on lower trunk. RMS was calculated for statistical purpose in AP and ML directions. Results showed a significant effect of an interaction on RMS excursion in ML and AP direction.

Research work shown that trunk play major role in stability control during standing and also walking (Gill et al. & Allum et al., 2001, Blackburn et al. 2003; Creath et al., 2005; Grabiner & Troy et al, 2005; Dingwell et al., 2008). There is less work done on trunk movement and its role in dual tasking while in standing position, but much research has been worked on trunk role in stability during walking. Trunk excursion during walking is contrary to Haggerty et al. (2012) and our findings. Their results showed that trunk excursion reduced during dual tasking while walking, and this is believed to control the balance and the stability to prevent falls. A similar finding has been reported by Dingwell et al. (2008). Trunk motions decreased when participants performed a visual Stroop test during treadmill walking. During the dual task condition, participants were presented with four words, each a different color. A large projection screen placed directly in front of the treadmill was used for this purpose. Participants were asked to verbally identify the color of the word (i.e., ignore the meaning of the word). The authors suggested that the reduction in trunk motion during the dual tasks condition was due to increased gaze stability required to see and identify the displayed words and colours, thus to minimize head motion. This would be achieved by reducing magnitude of trunk motion. A similar result was also observed in the study by Grabiner and Troy (2005); young adults were asked to perform a visual Stroop task (i.e., using a display monitor in front of the treadmill) while walking on a treadmill. They observed decreased step width variability in the dual task condition as compared to the walking only condition. While engaged in cognitive tasks that require visual tracking of small targets or reading, gaze stability is an important factor for clarity of the visual image and also to minimize the feeling of dizziness. During the visual tracking, the display provides an external spatial frame of reference that could be used to limit changes in body (trunk) position in space during the treadmill walking. Together these findings demonstrate that continuous walking is possible at the same time that clients can comfortably view a computer display, a convenient method to engage clients in different types and levels of cognitive demands. Some studies have found contrary results. Van Iserel et al. (2008) and Kang et al. (2010) have reported an increase in trunk motion while performing verbal fluency tasks such as backwards counting, serial subtraction, and arithmetic problems. Velocity transducers were used for recording the trunk excursion during over-ground walking. The increase in trunk motion in these studies might be due to the type of secondary task selected in those studies. It is very interesting to note that when a secondary task is verbal, then trunk motion does increase for dual-tasks condition compared to walk alone. However, the trunk motion decreased for dual task condition when secondary task is non-verbal (visual). This likely speaks to the power of gaze stability requirements, i.e., if the head moves randomly while walking, then vision will be degraded significantly.

Increasing trunk excursion in our findings could also be affected by our visual tracking task performance, so further consideration is also required on this issue.

3.3. Effect on visual performances:

Our results have revealed significant interaction effect for stability measures but no interaction effect was found for visual tracking performances. There is no study that has used visual tracking in dual tasking but several studies have used other secondary tasks that required attention and challenge cognitively. Similar results were also noted by Maylor et al. (2001). They were looking at the effect of postural position on cognitive performance. They used spatial and non-spatial memory tasks, based on Brooks (1967) as described in literature review. Correct response to the given task was noted as performance in cognitive task and a dependent variable for the same. Participants were asked to perform in the sitting and standing position. However, results did not show any significant influence of position on cognitive task performance as we found in present study.

These results are also supported by Huxhold et al. (2006). Their results were similar with our findings only for younger adults but not for older adults. In this study, 19 older adults (average 69 years) and 20 younger adults (average 25 years) participated and performed memory tasks in sitting and standing positions. They have used three different verbal-based cognitive tasks concurrently with sitting and standing. Cognitive tasks were differing on the level of their difficulty, which included choice reaction time task (first task), digit 2 back working memory task (second task), and spatial 2 back memory task (third task). In the choice reaction time task, participants were shown random 22 digits per trial ranging between 1 to 9 and the digits 1, 2, and 3 were assigned as targets. In the second task, participants were shown 22 digits per trial, from 0 to 9, and had to identify digits shown two-step back. In the third task, a dot appeared in a three-by-three grid, and participants were asked to tell identical location of dot presented 2 steps back. The response accuracy, reaction time, and unit-weight combined score of both were used to explain performance in cognitive domain. Their results have shown no significant effect of position on cognitive task performance. However, there results revealed that cognitive task difficulty level significantly influenced cognitive performance. They also found that older participants' performance was affected by position, sitting or standing, and older adults showed decreased accuracy and combined score and increased reaction in cognitive task performance compared to younger adults.

In contrast, there are many studies that revealed that any balance demanding task, standing or walking, has influence on cognitive task (secondary task) performances (Lajoie et al., 1993; Beauchet et al., 2005; Van Iersel et al., 2008; Yu et al., 2010). These discussed studies have used different cognitive tasks while in standing or walking; Lajoie et al. (1993) have used verbal response time, Dubost et al. (2006), Van Iersel et al. (2008), and Beauchet et al. (2005) have used verbal fluency tasks. However, there results showed that increasing balance demand significantly influenced cognitive performance. Yu et al. (2010) also found similarity in their visual vigilance task performance when they assess performance during rough balance condition.

CONCLUSION:

This study has revealed that properties of standing surface play a major role to maintain stability during standing as well as in visual tracking task performance. No significant effect of visual tracking task was observed on stability; however, increasing demand of visual tracking influences visual tracking performances. Our study also revealed a significant interaction between visual tracking task demand and increasing balance demand on stability measures. This indicates that changes in surface property will have more affect on balance/stability of humans, and it will be more challenged with more demanding secondary task. Because this study has been performed on healthy younger adults, we could not explain how older populations would react on this paradigm. So in future, it would be good to use the same paradigm for older populations to develop a balance assessment tool to find out fallers.

CLINICAL SIGNIFICANCE:

Balance is very important factor to execute daily living activities with out any injuries, especially in older age when motor and sensory system coordination becomes slow. Due to this slow response toward sudden environmental changes could lead to fall, which is a very big concern in older age. Slow recovery process and expensive medical support makes fall very serious issue. In present study, we looked how motor, sensory and higher function interact with each other and react towards such balance challenging situations. Therefore, this study will help to develop an assessment tool for faller and non-faller in community dwelling population. Not only that, this protocol would be helpful to rehabilitate coordination deficits neurological disorders and also helpful to teach progressive stability and coordination in TBI and Stroke conditions.

STRENGTH OF STUDY:

1. Tasks used in study were based on activities of day-to-day life, which involved balance and visual attention prospect.
2. Study looked on simple to complicated aspect of their domain whether it is physical load or visual tracking load.
3. Task protocols were not very time consuming. One task took thirty seconds to be completed.
4. Task protocol was simple and easy to understand and also easy to execute.

LIMITATIONS AND FUTURE IMPLICATIONS:

1. Current study involved only standing balance aspect but did not include dynamic aspect of balance, like walking, which is also important in daily living activities.
2. Likely too small of a sample size.
3. We are unable to generalize our results because our study is limited to healthy young adults. Future study should be conducted on older and frail older population.
4. Current study did not look on eye movements during visual tracking task performances to look on eye head coordination and its effects.

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