Measuring Human Balance on an Instrumented Dynamic Platform: A Postural Sway Analysis

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Abstract— **A system to monitor the trajectory and distribution of Center of Pressure (CoP) oscillations in real-time was designed. The system used a custom built force plate that measured sway area and sway velocity based on the measured CoP. A stable posture is reflected by a controlled CoP oscillation, where the oscillation lies within the limits of stability. Large magnitudes of CoP oscillations (large sway area) indicate weak proprioception strength and a heightened risk of falls. Experiments carried out involved self-induced perturbations that destabilized postural control among volunteers with active and inactive lifestyles. The observed results from the experiment indicate that individuals with active lifestyle have better postural control than individuals with inactive lifestyle. Subjects with active lifestyles demonstrated greater sway velocities, while maintaining a small sway area.**

Keywords—**postural sway, sways area, sway velocity.**

I. INTRODUCTION

Humans must be able to adequately balance themselves in order to perform basic acts of daily living (ADL). A good balance is result of a healthy integration of visual, proprioceptive and vestibular information by the central nervous system (CNS) to produce coordinated movements which maintain the Center of Mass (CoM) within the limits of stability. The ability of the CNS in maintaining balance is dependent on several factors such as: (1) task difficulty, (2) cognitive load [1], and (3) motor skill [2]-[3].

Liston and Brouwer examined postural control in 20 stroke patients using Balance Master [4]. They reported that dynamic balance measure is a better indicator of functional balance performance in stroke patients than static balance. Ferber-Viart et al. [5] used Equitest dynamic posturography in 195 healthy children and 64 young adults to observe balance maturation process. They concluded that children, due to incomplete development of vestibular system and central nervous system integration, have weaker postural control compared to young adults. Pereira et al. [6] examined the reliability and effects of different knee positions using Biodex Stability System. They reported that permitting slight knee flexion offered better stability than maintaining them locked in total extension. However, the major limitations of the devices for measuring human balance (The Balance Master, Equitest, Biodex Stability System and Kinesthetic Ability Trainer) are its high initial acquisition cost and its spatial restrictions as these devices require large space and are only limited to a dedicated laboratory/facility [7]. Therefore, in Gopalai et al. (2011), we studied the viability of using a force-sensing platform (FSP) to assess stability [8]. The study looked into the pressure concentration of the feet when subjects stood on flat surface and on a dynamic platform. The FSP approach addressed the cost and spatial restriction of the commonly used devices but was unable to study the sway velocity due to limitations in sensing methods.

This study aims to use CoP measurements as basis for quantifying postural control. The work presents a custom-built force plate which monitors sway velocity and area by using four load cells. Sway area and sway velocity are crucial parameters in quantifying human body balance, as it reveals the control mechanism employed by individuals. This paper also investigated the significance of active and inactive lifestyle in postural control, by monitoring the sway area of subjects standing on the dynamic platform with eyes open (EO) and eyes closed (EC) [9].

II. METHODOLOGY

Instrumented Dynamic Platform

BOSU Balance Trainer (Ball, Bounce and Sport Inc) is a balance training device that helps achieving body balance in a faster yet safer way. This device has diameter of 635 mm and a variable height of x mm, depending on the amount of air inflated into its inflatable chamber. In this context, BOSU Balance Trainer is referred as the dynamic platform as it has an uneven surface on which subjects will stand during the experiment.

A force plate was designed and developed to measure the total amount of force exerted on the force plate and to de-

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termine the sway area and sway velocity. This force plate has a dimension of 45.45 cm x 45.45 cm x 2.2 cm with four button load cells (FUTEK, Inc) placed equally apart at four corners. Each load cell has a measuring range up to 45 kg with nonlinearity of ±0.5%. Hence, the force plate can measure a load up to 180 kg, assuming equal distribution to all four load cells. The load cells have a sampling rate of 200 Hz. This force plate was designed to be mounted on the BOSU balance trainer or on a flat surface.

Definition of Sway Area and Sway Velocity

Center of pressure (CoP) is defined as the point of application of the total Vertical Ground Reaction Force (VGRF). It is also defined as the point, where the resultant of vertical force components intersects the support surface. In this study, it is mathematically expressed in (1)-(3).

$$X_{CoP} = \frac{x}{2}\left(1 + \frac{\left(F_{xo} + F_{xy}\right) - \left(F_{oo} + F_{oy}\right)}{F_y}\right) \quad (1)$$

$$Y_{CoP} = \frac{y}{2}\left(1 + \frac{\left(F_{oy} + F_{xy}\right) - \left(F_{oo} + F_{xo}\right)}{F_y}\right) \quad (2)$$

$$F_y = F_{oo} + F_{xo} + F_{xy} + F_{oy} \quad (3)$$

where F_Y is the sum of all forces measured by the load cells, and X_{CoP}, Y_{CoP}, F_{oo}, F_{xo}, F_{xy}, and F_{oy} are depicted in Figure 1.

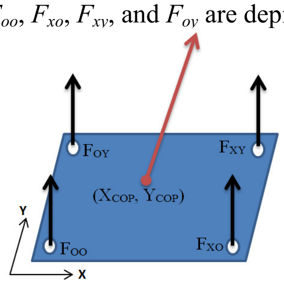


Figure 1. Location of CoP and the magnitude of vertical resultant force determined from load cell measurements

The trajectory of CoP over a period of time has been accepted as performance indicator of human postural control and a precursor to fall [10]-[14]. Two parameters, which utilized the trajectory of CoP are used in this study to examine postural stability of individuals with active and inactive lifestyle. The first parameter is the sway area. Sway area is defined in (4)-(6), where *t = 1, 2, 3, 4… T*.

$$Sway\_Area = \sum_{t=1}^{T-1} \frac{1}{2}\left[A - B\right] \quad (4)$$

$$A = X_{CoP}\left(t\right) Y_{CoP}\left(t+1\right) \quad (5)$$

$$B = X_{CoP}\left(t+1\right) Y_{CoP}\left(t\right) \quad (6)$$

The second parameter is the sway velocity. Sway velocity reflects the response of neural muscular system in balancing human body. It is defined as the ratio of the Euclidean distance between two successive CoP on a stabilogram and the sampling time, t_{sample} = 0.05 s, as described in (7)-(9).

$$Sway\_Velocity = \frac{1}{t_{sample}} \sqrt{\Delta X_{CoP}^2 + \Delta Y_{CoP}^2} \quad (7)$$

$$\Delta X_{CoP}^2 = \left[X_{CoP}\left(t+1\right) - X_{CoP}\left(t\right)\right]^2 \quad (8)$$

$$\Delta Y_{CoP}^2 = \left[Y_{CoP}\left(t+1\right) - Y_{CoP}\left(t\right)\right]^2 \quad (9)$$

Experimental Procedure

A total of 13 normal and healthy individuals participated in this study. Experimental objectives and procedures were explained to them before they give their consent to take part in this study. All subjects had no prior exposure to the BOSU balance trainer.

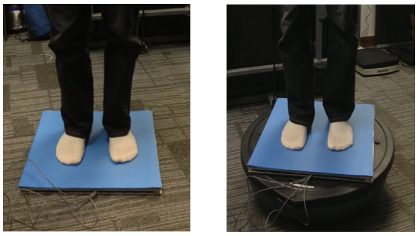
Subjects were categorized into two categories: (1) Individuals with active lifestyle and (2) Individuals with inactive lifestyle. Individuals with active lifestyles are classified as those who do sports/exercises three times a week (or more). Individuals with inactive lifestyle are those who do sports/exercises less than three times a week (or none). Based on these criteria, nine subjects were inactive (Age: 24.25 ± 3.01 years old, height: 171.96 ± 7.01 cm, and weight: 64.80 ±6.09 kg) and five subjects were active (Age: 26 ± 3.81 years old, height: 171.48 ± 5.77 cm, and weight: 72.44 ± 9.51 kg).

Subjects' ability to maintain body balance and postural control in EO and EC states were tested on flat surface and on the dynamic platform. Safety hand rails were introduced to assist subjects mount the balance trainer and served as support in event subjects lose balance during data acquisition, subject's vertical projection of force was then recorded for the following conditions:

1) Flat Surface: Subjects were required to maintain body balance for 60 s in EO while standing motionless on the force plate, followed by a second set of readings for 60 s in EC, Figure 2(a). This arrangement was alternated between acquisitions for three pairs of EO and EC readings. Subjects were allowed to take breaks in between each pair of acquisition. Readings were acquired when subjects were standing comfortably above the platform.

2) Dynamic Platform: Subjects were required to mount the BOSU balance trainer fitted with the force plate, Figure 2 (b), for 60 s in EO, followed by the similar activity for 60 s

in EC. Breaks were introduced between each pair of readings (EO and EC), to minimize the effect of fatigue on postural sway. Data was logged for three pairs of readings. Readings were acquired when subjects were standing comfortably above the platform.



(a) (b)

Figure 2. Standing still on (a) a flat surface and (b) the dynamic platform.

III. Results

Postural sway of a subject standing on a flat surface and on the dynamic platform is presented in Figure 3 and Figure 4. No significant difference is found between active and inactive groups' sway area and sway velocity when they stand on the flat surface in EO (Figure 5 and Figure 6). However, when they close their eyes, differences between active and inactive groups were apparent. Active group has average sway area of 83.64 mm^2 whereas the inactive group has average sway area of 160.59 mm^2. This result implies that active group has better neuro-muscular control over their posture in the absence of visual cues, compared to inactive group. Individuals with active lifestyle do not rely heavily on visual proprioceptors to balance themselves. This is apparent when they stand on the dynamic platform. The sway area of active group in EO and EC are 719.73 mm^2 and 1979.53 mm^2 respectively while inactive group has sway area of 941.19 mm^2 and 2070.77 mm^2.

Sway velocity exhibits slightly different behavior. Difference between active and inactive group is only apparent when the subjects stand on the dynamic platform with EC. Active group has greater sway velocity than inactive group. However, despite having greater sway velocity, active group has smaller sway area. This result suggests that active group has quicker response in maintaining their balances within the stability limit and in minimizing postural sway compared to inactive group.

Other than differences between active and inactive groups, relooking at Figure 5 and Figure 6, one can observe the increasing trend of sway area and sway velocity. Significant increase in sway area and sway velocity is found in EC while the participants stand on the platform. It can be twice as much as the value found in EO experiments. This result suggests that human CNS is highly challenged when it is subjected to postural balance on a dynamic platform without the assistance of visual proprioceptors.

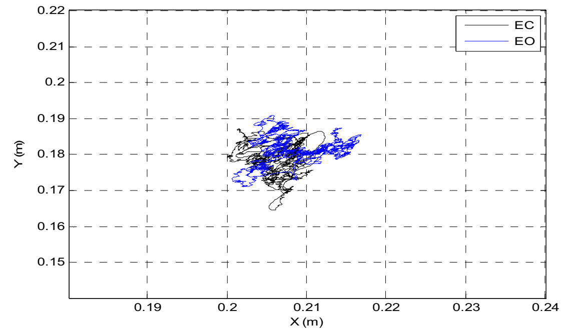


Figure 3. Postural sway of a participant on a flat surface with EO (blue) and EC (black) for duration of 60 s

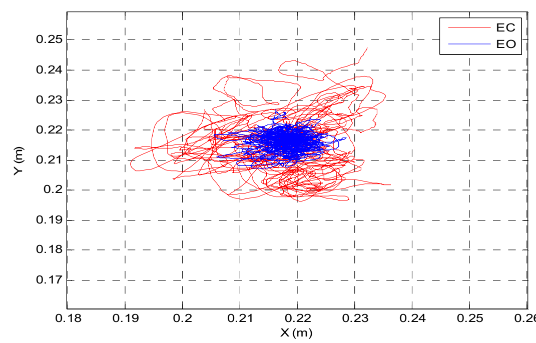


Figure 4. Postural sway of a participant on a dynamic surface with EO (blue) and EC (black) for duration of 60 s

IV. Disscusions

Force plate provides a good estimation on how humans balance themselves while performing their daily routines. Unlike conventional approach, where sophisticated devices are employed to examine a person's capability in balancing himself/herself in different circumstances, this study utilized a commonly available dynamic platform i.e. BOSU balance trainer and a custom-built force plate to examine human postural control in the absence of visual cue.

With dynamic platform, body imbalance can be quickly identified: One side of the platform will be lower than the other if unequal forces are applied to the platform. At present study, if the platform is tilted in medial-lateral direction, one foot has to exert greater net force to compensate the tilt so that the platform can be leveled again. If it is tilted in anterior-posterior direction, the subject has to sway forward or backward to adjust his/her CoM. Individuals with active lifestyle have good coordination in balancing themselves on this platform. Current finding suggests that their CNS plays active role in responding to tilted platform (acquiring relevant inputs from different proprioceptors) and devises a compensatory mechanism to counter the tilt by displacing CoM and CoP appropriately. It also suggests that individuals with active lifestyle have faster response to counter this effect whilst reducing the body sway.

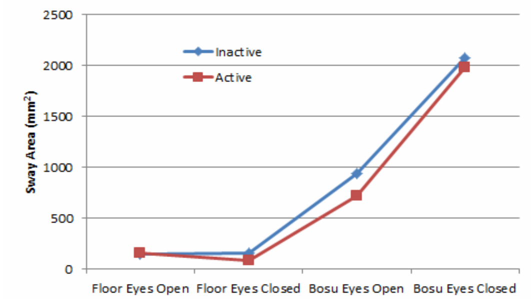


Figure 5. Average sway area of volunteers at different activities.

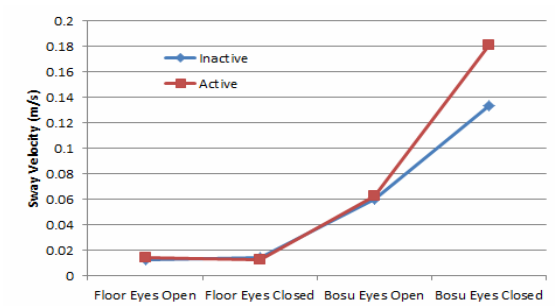


Figure 6. Average sway velocity of volunteers at different activities.

It is important to note that almost all of the participants were not able to maintain their posture for 60 s on the dynamic platform. Considering this is the first time they stand on such platform, it is acceptable. However, it raises several concerns: (1) If all of them are able to balance themselves for 60 s, how would it affect the sway area and sway velocity? (2) If they are allowed to have several practice sessions to maintain their posture up to 60 s, how much will it improve their postural control?

V. Future work and conclusions

Although this study has provided an initial understanding on how active and inactive individuals behave in maintaining their body balances while standing on the dynamic platform, it is believed that more experimental data need to be collected to provide more reliable results. Better classification can be implemented to provide accurate representation of the individuals with active lifestyle, such as type of routine exercises performed by the participants and duration of each activity in a week. Further investigation can also be carried out to examine which joint movement(s) contributes to the body stability when a person stands on the dynamic platform.

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