Chapter 87
A Preliminary Study on Effects of Vision, Standing Posture and Support Surface on Human Balance

Shu-ping Xiong and Mubashir Karim

Abstract A preliminary experimental study on examining the effects of vision, standing posture and support surface on human balance was conducted. Planar deviation (PD), a parameter derived from recordings of center of pressure (CoP) with the aid of a static force platform, was used to assess the body sway and thereby human balance. The experimental results showed that PD had moderate to high short-term test-retest reliability and all main effects from three factors were significant, all interaction effects were not significant except the vision*support surface. The implications of these findings and future research directions were discussed.

Keywords Human balance • Center of pressure • Fall risk • Reliability

Introduction

Due to two thirds of a person's body mass is located at two thirds of body height above the ground, the humans as bipeds are inherently unstable systems unless the body posture is continuously controlling to maintain it (Winter 1995). Human balance is maintained through the integration of at least three major sensory systems: the vision, vestibular, and the proprioceptive systems (Winter 1995; Redfern et al. 1997). The vision system provides vital information about the body's position in relation to the surroundings, and the vestibular system senses linear and angular accelerations. The proprioceptive system senses the position and velocity of all body segments as well as their contact with external objects such as the ground (Winter 1995).

S.-p. Xiong (✉) • M. Karim
Ergonomics and Applied Biomechanics Laboratory, School of Design and Human Engineering, Ulsan National Institute of Science and Technology, Ulsan, South Korea
e-mail: maverickhkust@unist.ac.kr

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Millions of people experience dizziness and balance problems in their lifetimes, especially for the elderly and certain patients due to the degeneration of the balance control system (Raymakers et al. 2005; Borah et al. 2007). With the increase in our ageing population, injuries and loss of life due to falls in the elderly is becoming a major public health issue. Thus, understanding the affecting factors and the mechanism of human balance control system is important.

Traditionally, the effects of various factors including vision, standing posture, support surface, age, healthy condition, etc. on human balance have been studied independently using different methods (Redfern et al. 1997; Borah et al. 2007; Paulus et al. 1984; Uimonen et al. 1992; Prieto et al. 1996). In general, the ground reaction forces beneath the feet of an individual and moments in different test conditions were recorded by force plates, which were then used to derive the centre of pressure (CoP). Different parameters to characterize the variability of CoP were developed for assessing the human body sway and thereby body balance. For example, planar deviation (PD), a commonly used parameter for measuring human balance from CoP data, was defined as the square root of the sum of variances of CoP displacements in X (sideways) and Y (fore-aft) directions (Raymakers et al. 2005). Consequently, a larger PD value indicated the greater balance difficulty.

One major limitation of the aforementioned one-factor-at-a-time approach is lack of ability to investigate the potential interaction effects among different factors. Since our balance system utilizes information from different sources which may not be always matched with each other (Redfern et al. 1997), this mismatch may induce significant interaction effects on human balance. Consequently, the primary objective of this study was to systematically evaluate the effects (including interaction effects) of vision, standing posture and support surface on human balance. The reliability of using PD as a balance measure was also investigated because in spite of the frequent use of different measures from CoP for assessing the human balance, only a couple of studies have reported on their reliabilities (Condron and Hill 2002; Swanenburg et al. 2008; Ruhe et al. 2010).

Methodology

Participants

Ten young healthy adults were recruited for this experiment. Their ages ranged between 20 and 32 years with an average age of 23.2 years (SD = 4.5 years). The ranges of body stature and weight were from 160 to 190 cm (average: 174.4 cm) and 51 to 89 kg (average: 67.8 kg) respectively. All participants gave informed consent to participate.

Experimental Design, Apparatus, and Procedure

A 2 vision levels (eyes close, eyes open)* 2 standing postures (single-leg stance, two-leg stance) * 2 support surfaces (soft surface, firm surface) within-subject full factorial design was used. Two successive trials with a break of 60 s in between were performed so that all possible interaction effects among different factors can be investigated and the test-retest reliability of PD can be evaluated as well. The presentation sequences were randomized to minimize any order effect. A static force platform (AMTI model OR6-7, USA) was used to record ground reaction forces and moments for 60 s (Carpenter et al. 2000; Clair and Riach 1996) with a sampling frequency of 100 Hz for each experimental condition (Ruhe et al. 2010).

The basic instruction consisted of asking each participant to barefoot stand as steady as possible, with his/her arms at the sides in a comfortable position (Lafond et al. 2004). The outlines of the standing feet were traced in order to obtain standardized individual foot positions for the repeated measurements so that the influence from different positions of feet can be minimized (Uimonen et al. 1992). With eyes open, the participants were required to visually fix a black spot of 10 cm diameter on a portable whiteboard 150 cm before them at their eye heights (Raymakers et al. 2005). A foam seat pad of 4 cm thickness was placed directly on the force platform where the participant stood, in order to simulate the condition when the participant standing on the soft support surface.

Data Analysis

Excel program was used to calculate the CoP data and human balance parameter PD. The intra-class correlation (ICC), a measure for absolute agreement (Shrout and Fleiss 1979), was used to check the test-retest reliability of PD measures from two trials. After that, a three-way repeated measures analysis of variance (ANOVA) was performed to evaluate the effects of vision, standing posture and support surface on human balance using the PD measurement. The software SPSS (v16.0) was used for all statistical analyses. P values less than 0.05 were considered statistically significant.

Results

Test-Retest Reliability of Planar Deviation (PD)

ICC values on planar deviation (PD) were 0.72 for single measure (ICC(2,1)) and 0.84 for average measure (ICC(2,2)) respectively. Since it is generally accepted that moderate ICC value should be above 0.4 and a good ICC value should be larger

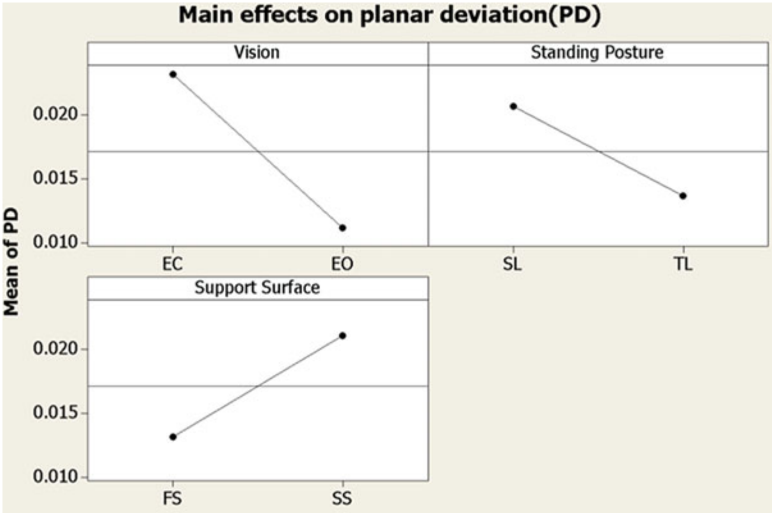

Fig. 87.1 Main effects of three factors on human standing balance measure PD (unit: m) *EC* eyes close, *EO* eyes open, *SL* single-leg stance, *TL* two-leg stance, *FS* firm support surface, *SS* soft support surface

than 0.75 (Ruhe et al. 2010; Carpenter et al. 2000; Clair and Riach 1996; Lafond et al. 2004; Shrout and Fleiss 1979; Xiong et al. 2011), PD can be considered as a reliable parameter for measuring the human balance.

Effects of Vision, Standing Posture and Support Surface on Human Balance

The plots shown in Figs. 87.1 and 87.2 illustrated three factors' main effects and their interactions on PD respectively. The main effect plot indicated that vision ability (eyes open, EO) improved the standing balance and two-leg stance (TL) on the firm support surface (FS) was more stable (Fig. 87.1). Regarding the interaction effects (Fig. 87.2), the lines in each cell of the interaction plot were roughly parallel except the lines for the interaction between vision and support surface, indicating the potential existence of an interaction effect between vision and support surface. ANOVA test (see Table 87.1) further confirmed that there were significant main effects from all three factors ($P < 0.05$), all interaction effects are nonsignificant ($P > 0.05$) except vision*support surface ($P = 0.004$). The vision*support surface interaction (Fig. 87.2) showed that even though the human standing balance on the soft surface (SS) was comparable with that of the firm surface (FS) when vision was available (eyes open, EO), without vision input (eyes close, EC), human standing on the soft surface was much less stable than that of the firm surface.

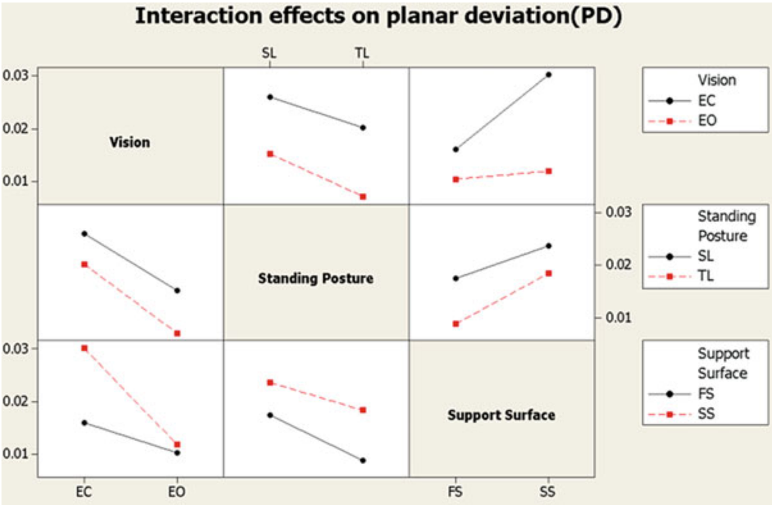

Fig. 87.2 Interaction effects of three factors on human standing balance measure PD (unit: m) (Same abbreviations are used as Fig. 87.1)

Table 87.1 Anova results on human balance measure PD (unit: m)

Source	DF	MS	F	P[a]
Vision (V)	1	0.00576	31.65	**0.000**
Standing posture (P)	1	0.00195	10.71	**0.001**
Support surface (S)	1	0.00248	13.64	**0.000**
Subject (block)	9	0.00106	5.83	**0.000**
V*P	1	0.00005	0.28	0.599
V*S	1	0.00160	8.78	**0.004**
P*S	1	0.00012	0.65	0.422
V*P*S	1	0.00069	3.77	0.054
Error	143	0.00018		**0.000**
Total	159			**0.001**

[a]P values less than 0.05 are shown in bold

Discussion

Even though the evaluation of CoP variability from force platforms is a commonly used method for diagnosing balance problems early and assessing the intervention effects on treating these problems (Chaudhry et al. 2005), the reliability of CoP measures needs to be determined at first if studies using this method are to be considered as valid (Ruhe et al. 2010). In the present study, the test-retest reliability of a commonly used human balance measure PD was investigated. The reliability coefficients (ICC) were above 0.70 for single measure (trial) and above 0.80 for average measure of two trials, which indicated moderate to good test-retest reliability. The ICC values in this study were quite comparable and slightly higher than the corresponding data (around 0.60 and 0.75 for single measure and average measure of two trials respectively) reported in (Lafond et al. 2004). The slight improvement on reliability coefficients from this study could be due to a shorter time interval (1 min) between trials was used in this study when compared with (Lafond et al. 2004) (~5 min). Of course, different experimental protocols may also contribute to the slight difference on reliability coefficients. Nevertheless, the reliability test results were in line with the suggestion of using two or three trials with at least 60 s trial duration for signal stationary and the good reliability of the CoP measures (Lafond et al. 2004).

The experimental results from this study clearly demonstrated that all three investigated factors can significantly affect the human standing balance. As expected and consistent with most previous studies, vision input can improve our balance and two-leg stance is more stable. Regarding the factor of support surface, even though it was reported in the human factors literature that soft support surfaces such as floor mats (so-called anti-fatigue mats) generally resulted in less discomfort and fatigue than on firm support surfaces such as hard concrete floors (Cham and Redfern 2001), this study showed that standing on soft support surfaces negatively affect the standing balance. Compared with the firm support surface, the soft support surface may reduce proprioceptive inputs or provide erroneous proprioceptive cues from feet to the postural control system (Redfern et al. 1997). Furthermore, even though the effect of standing posture on human balance measure PD was independent from different conditions of vision and support surface, the interaction between vision and support surface was significant (Fig. 87.2 and Table 87.1). With open eyes, human standing balance on the soft surface was somewhat comparable with that on the firm surface, but with closed eyes, human standing balance on the soft surface was reduced dramatically. Thus, the effect from different support surfaces on human standing balance was much greater with closed eyes when compared with open eyes.

One implication of aforementioned results is that caution should be taken when placing different floor mats on the ground for the purposes of comfort and anti-fatigue. Even though softer support surfaces are more comfortable and can reduce the potential for fracture neck of femur in the event of a fall, the potential for destabilizing human balance and increasing the risk of fall may cancel out the benefits (Redfern et al. 1997; Raymakers et al. 2005; Borah et al. 2007; Paulus et al. 1984; Uimonen et al. 1992; Prieto et al. 1996; Condron and Hill 2002; Swanenburg et al. 2008; Ruhe et al. 2010; Carpenter et al. 2000; Clair and Riach 1996; Lafond et al. 2004; Shrout and Fleiss 1979; Xiong et al. 2011; Chaudhry et al. 2005; Cham and Redfern 2001). This is true especially for the elderly who generally have poor visibilities and difficulties in motor and muscle control to balance their bodies. Additionally, these findings demonstrated a comprehensive consideration of different factors and their interactions is needed for assessing the human balance.

Several limitations do exist in this preliminary study on human standing balance. Firstly, the sample size (N = 10) in this study is relatively small, thus the statistical power of this study may not be sufficient to detect every possible significant effects. Secondly, due to the break between two trials was 1 min only, the test-retest reliability of human balance measure PD in this study can be considered as the short-term reliability only, the long-term reliability should be established further. Thirdly, a follow-up study on the detail configurations (stiffness, thickness etc.) of soft support surfaces should be conducted for finding an appropriate configuration with certain level of comfort and low risk of fall. Additionally, further research into the role of all factors in human balance should include study the human dynamic activities such as walking as well as use different balance parameters.

Conclusion

A preliminary experimental study on examining the effects of vision, standing posture and support surface on human balance was conducted with the aid of a static force platform. The results showed that all three factors have significant main effects on standing balance. In particular, vision ability improves the standing balance and two-leg stance on the firm support surface is more stable. Significant vision*support surface interaction was also found. The implications of the findings were discussed and future research directions were outlined.

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