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Research Article

Impact of Gender, Change of Base of Support, and Visual Deprivation on Postural Balance Control in Young, Healthy Subjects

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Abstract

Background: Vision, vestibular sense, proprioception and muscle strength are required to maintain balance. However, gender could also play a crucial role in postural sway.

Objectives: This study was used to examine (i) the impact of gender, surface type, and vision on postural sway; (ii) the effects of gender and vision on the limb symmetry of postural sway; and (iii) to understand the effects of gender, stance, surface type and vision on the alterations of dynamic postural sway alterations.

Methods: This was a cross-sectional study in which young, healthy men ($n = 15$) and women ($n = 12$) underwent a balance control assessment using a force plate (SATEL, 40 Hz). Postural stances were evaluated in different conditions: Opened eyes (EO) and closed eyes (EC), on different surface foam vs. firm, a dominant leg stance (DL) vs. a non-dominant leg stance (NDL), and a mediolateral stance (ML) vs. an anteroposterior stance (AP). The mediolateral sway (ML sway), anteroposterior sway (AP sway), and sway area were calculated from the centre of pressure displacements.

Results: ML sway, AP sway and sway area increased when eyes were closed ($P < 0.000$). Foam surface perturbs balance control more than firm surface under EO and EC conditions for both genders, as observed in the AP sway curve ($P < 0.000$). A functional symmetry exists between the DL and NDL for all sway parameters: The ML sway, AP sway, and sway area ($P = 0.720$; $P = 0.292$; $P = 0.954$). The AP stance is more stable for the ML sway than the ML stance for both genders ($P < 0.001$). For the AP sway, the ML stance is more stable than the AP sway AP direction stance for both genders ($P < 0.001$). Women were significantly more stable than men in the ML stance when vision was absent ($P < 0.01$).

Conclusions: Postural sway was altered more significantly on a foam surface than on a firm surface and symmetry between the DL and NDL was observed. Furthermore, we concluded that women have better dynamic balance control than men.

Keywords: Posture, Balance, Functional Symmetry, Visual Condition, Gender Differences

1. Background

Proprioception, vision and the vestibular systems are necessary to provide the information required to maintain balance (1). Standing on a compliant surface (foam surface), on one leg (dominant or non-dominant leg), or closing one's eyes can perturb this balance (2, 3)

Few studies have investigated the effects of gender on balance control while taking into account the surface (firm and foam), visual structure (eyes open and eyes closed), bipedal or unipedal stance (dominant leg stance and non-dominant leg stance), but the findings are controversial (4, 5). Gender and vision represent potent factors that may influence postural sway (4). Several studies assessed the combined effects of gender and limb dominance on postural sway, and the results were controversial (5-7). Clarification of the effect of limb dominance, gender and vision on postural sway could offer relevant information for clinicians on the characteristics of men and women's physical fitness and be helpful in the rehabilitation field (8). However, as we know, there are not sufficient study has explored the impact of gender on the symmetry between dominant and non-dominant limbs for healthy young individuals.

Considering that the type of stance differs significantly between firm and foam surfaces, the ability to maintain balance evaluated in the two stances may vary (2). The ability to maintain balance during each stance and the addition of other factors such as gender, surface and vision should be explored (2). However, the relationship between balance control during each stance and gender and vision has not been examined yet. Few studies showed that females were more stable than men (9, 10), while other studies showed no difference between sexes in dynamic balance control (11-13). However, no study to date has compared anteroposterior (AP) and mediolateral (ML) dynamic postural control combined with gender and vision factors in young, healthy individuals.

2. Objectives

Our study aimed: (1) to investigate the impact of gender, the surface type, and vision on postural sway; (2) to assess the impact of gender and vision on the limb symmetry postural sway; and (3) to understand if the alterations to the dynamic postural sway are depended on gender, directional stance and vision. We hypothesised that (1) females would have better balance sway than males; (2) postural stance would be altered when the base of support is changed or reduced; and (3) postural sway would increase without visual information.

3. Methods

3.1. Participants

Twenty-seven healthy, young volunteers aged between 18 and 25 years (15 men, 12 women) volunteered to participate in the study. Table 1 details the anthropometric and body composition measurements of the participants. Exclusion criteria were: A history of balance problems (ie, vestibular or neurological problem), lower limb musculoskeletal disorder (ie, surgery, injury or pathology at the lower limb), spinal surgery, and pregnant women. Also, young volunteers who majored in sports were excluded because they may bias the statistics results. All participants were required to refrain from consuming alcohol, caffeine or any medication that could affect performance and avoid strenuous exercise for at least 24 hours before testing. Before participating, participants were asked to give their written informed consent and were informed about the objective of our study. The study was approved by the hospital ethics committee and conform to the principles of the Declaration of Helsinki (1964). A physical activity questionnaire and medical history questionnaire to determine eligibility were completed.

3.2. Measurements

The tests were performed between 10:00 AM and 12:00 PM in the Department of Physical Medicine and Functional Rehabilitation. All assessments were performed under identical laboratory conditions and by the same examiners. All subjects' physical characteristics were measured, including body height, weight, and body mass index (BMI). Body height was measured using a stadiometer. Body weight, Lean body mass (LBM), body fat (BF) and body fat percentage (%BF) were evaluated by Tetrapolar bioelectrical impedance analysis (Tanita1-TBF-300 model). BMI was calculated by dividing body weight (kg) by the square of body height (m^2).

3.3. Posturographic Assessment

Participants underwent a posturographic evaluation of static balance (bipedal and unipedal stance) and dynamic balance by the use of a stabilometric platform (SATEL). This platform is composed of a steel plate maintained by three tri-axial transducers with a sampling rate of 40 Hz (14, 15). Participants stood shoeless on a force platform within the Romberg's position (feet abducted at 30°, heels set apart by way of 3 cm), their arms striking loosely via their sides. In the EO situation, subjects were informed to look straight ahead at a white pass placed onto the wall 2 m away at eye level. In the EC situation, they were instructed to keep their gaze horizontal in a straight-ahead direction. During the registering session, the experimenter was positioned next to the subjects to control security without touching them or provide further instructions and insist that the posture was preserved throughout the trials. A rest period of 2 minutes was provided between 3 types of tests (bipedal, unipedal, and dynamic) to cancel fatigue effects.

3.4. Bipedal Balance Control

The participants were asked to stand barefoot on the platform in the following conditions: Firm surface with EO or EC, Firm-EO, Firm-EC respectively, foam surface with EO or EC, Foam-EO, Foam-EC; respectively. All trials lasted 30 seconds and were initiated with eyes open. Each participant repeated the four conditions three times in a randomized order and the average was used in the statistical analysis. A rest period of one minute was provided between measurements to avoid fatigue.

Table 1. Anthropometric and Body Composition Measurement [a]

Parameters	Women	Men	*t* Value	P-Value
Age (y)	21.08 ± 2.43	20.46 ± 4.06	0.46	0.648
Body height (cm)	165.33 ± 3.45	175.33 ± 10.13	-3.26	0.003
Body weight (kg)	57.04 ± 8.99	72.69 ± 15.07	-3.17	0.004
BMI (kg/m^2)	20.85 ± 2.95	23.63 ± 4.68	-1.79	0.086
%BFM	23.78 ± 8.03	16.47 ± 7.98	2.36	0.027
BFM (kg)	14.2 ± 6.37	11.63 ± 6.92	0,99	0.331
LBM (kg)	42.85 ± 3.4	59.91 ± 10.19	-5.54	0.000

Abbreviations: BMI, body mass index; BFM, body fat mass; %BFM, percentage body fat mass; LBM, lean body mass.

[a] Data are presented as mean ± standard deviation.

3.5. Unipedal Balance Control

Participants were standing on one leg in the following four conditions in a randomized order: The dominant leg with EO (DL-EO); the dominant leg with EC (DL-EC); the non-dominant leg with EO (NDL-EO); and the non-dominant leg with EC (NDL-EC). The subject was informed to keep the non-test leg in hip flexion at 0° and knee flexion at 90°. Three trials with thirty-second each one, were registered for each leg, with a one-minute rest between each trial. The trials were performed on a firm surface. The kicking leg was defined as the dominant leg and the other leg as the non-dominant leg.

3.6. Dynamic Balance Control

For the dynamic balance situation, participants stood on a seesaw (radius of 55 cm and arrow of 6 cm) located at the platform either in the ML or in the AP direction (16). The platform turned into degree with the surrounding ground.

Participants were asked to face as nevertheless as possible on the platform with their hands comfortably placed downward at both side of the body, their bare feet separated by an angle of 30° and their heels positioned five cm apart (14). A plastic device provided with the platform turned into used to keep the same foot positions for all the balance measurements. Those conditions have been described as follows: ML dynamic direction stance with EO (dyn-ML-EO), ML dynamic direction stance with EC (dyn-AM-EC), AP dynamic direction stance with EO (dyn-AP-EO), and ML dynamic direction stance with EC (dyn-AP-EC). Each trial lasted 30 sec. Each participant repeated the four conditions in randomized order three times and the average was used in the statistical analysis. A rest period of one minute was provided between measurements to avoid fatigue.

3.7. Data Analysis

To assess the postural control of individuals, three postural variables were considered. CoP is a bivariate parameter that consists of fluctuations alongside the medial-lateral (ML sway) direction and alongside the anterior-posterior (AP sway) direction over time (17). The sway area (mm^2) is represented by the 95% confidence ellipse area. The recording was started once the subject was ready. Testing was cut off if the subject experienced any loss of balance. malfeasances were not scored.

3.8. Statistical Analysis

Variables were presented as means (standard deviations). Normality (Shapiro-Wilk-Test) and equality of variance (Levene-Test) were tested. When normality and equality of variance were ensured, an independent sample *t*-Test Student was conducted to compare two groups, and a three-way ANOVA ($2 \times 2 \times 2$) was used to compare between factors. For bipedal static balance control, factors were gender: Men and women, surface stance: Firm, foam, and vision: EO, EC. For unipedal static balance control, factors were gender: Men and women, dominance leg: Dominant leg (DL), non-dominant leg (NDL), and vision: EO, EC). For dynamic balance control, factors were gender: Men and women, direction stance: AP stance, ML stance, and vision: EO, EC. If significant main effects or interactions were present, we used the Bonferroni post-hoc procedure. The SPSS software statistical package (SPSS Inc., Chicago, IL, version. 16.0) was used to perform statistical analysis. The level of significance was set at $P < 0.05$.

4. Results

4.1. Body Composition

No significant differences were observed between women and men regarding age, BMI, and body fat mass. Still, body height, body weight, % BFM, and LBM were significantly different between both genders (Table 1).

Table 2. Three-way ANOVA of CoP Parameters Under Static (Bipedal and Unidepal) and Dynamic Balance Control

	ML Sway			AP Sway			Sway Area		
	F Ratio	**P-Value**	η_p^2	**F Ratio**	**P-Value**	η_p^2	**F Ratio**	**P-Value**	η_p^2
Static bipedal balance control									
Gender	1.85	0.185	0.068	3.85	0.060	0.133	0.902	0.351	0.034
Surface	0.13	0.720	0.005	122.93	0.000	0.831	51.416	0.000	0.672
Surface × gender	1.71	0.202	0.064	0.44	0.509	0.017	0.412	0.526	0.016
Vision	89.31	0.000	0.781	76.13	0.000	0.752	15.77	0.000	0.386
Vision × gender	0.15	0.693	0.006	0.31	0.580	0.012	0.140	0.710	0.005
Surface × vision	0.05	0.819	0.002	43.42	0.000	0.634	17.238	0.000	0.408
Surface × vision × gender	0.03	0.860	0.001	0.33	0.56	0.013	0.070	0.792	0.002
Static unipedal balance control									
Gender	1.850	0.185	0.068	1.51	0.229	0.057	0.014	0.906	0.000
Dominance	0.131	0.720	0.005	1,15	0.292	0.044	0.003	0.954	0.000
Dominance × gender	1.717	0.202	0.064	0.01	0.89	0.000	0.022	0.883	0.000
Vision	89.315	0.000	0.781	82.06	0.000	0.766	38.657	0.000	0.607
Vision × gender	0.159	0.693	0.006	0.36	0.552	0.014	0.000	0.978	0.000
Surface × vision	0.053	0.819	0.002	0.00	0.984	0,000	0.003	0.956	0.000
Dominance× vision × gender	0.031	0.860	0.001	0.06	0.805	0.002	0.813	0.375	0.031
Dynamic balance control									
Gender	5.89	0.022	0.19	5.53	0.026	0.18	4.91	0.035	0.164
Direction	89.37	0.000	0.78	47.05	0.000	0.65	8.59	0.007	0.255
Direction × gender	4.47	0.044	0.15	0.18	0.673	0.00	2.64	0.116	0.095
Vision	77.68	0.000	0.75	56.38	0.000	0.69	85.03	0.000	0.772
Vision × gender	0.02	0.864	0.00	0.00	0.995	0.00	3.25	0.083	0.115
Direction× vision	23.35	0.000	0.48	9.43	0.005	0.27	0.97	0.332	0.037
Direction× vision × gender	3.24	0.083	0.11	1.36	0.253	0.05	3.43	0.075	0.120

4.2. Bipedal Balance Control

Three-way ANOVA (Table 2) showed a significant impact of surface for AP sway and sway area, and a significant main impact of vision for all parameters: ML sway, AP sway, sway area. Furthermore, three-way ANOVA (Table 2) showed only significant surface x vision interaction for AP sway and sway area.

The post hoc analysis showed that ML sway (Figure 1A), AP sway (Figure 1B), and sway area (Figure 1C) increased significantly when vision was removed in comparison with EO ($P < 0.000$). In addition, AP sway (Figure 1B) was significantly higher in foam-EO and foam-EC than firm-EO and firm-EC, respectively for men and women ($P < 0.000$). The sway area (Figure 1C) was significantly higher in foam-EO and foam-EC than firm-EO and firm-EC for men, respectively and only higher in foam-EC than firm-EC for women ($P < 0.000$).

4.3. Unipedal Balance Control

The three-way ANOVA (Table 2) demonstrate a significant main impact of vision for all parameters: ML sway, AP sway, and sway area. No significant interaction was detected ($P > 0.05$).

Post hoc analysis showed ML sway (Figure 2A), AP sway (Figure 2B), area sway (Figure 2C) increased significantly when vision was removed in comparison with eyes opened ($P < 0.000$).

4.4. Dynamic Balance Control

The three-way ANOVA showed a significant main effect of gender: ML sway, AP sway, sway area; direction stance: ML sway: AP sway, sway area; and vision: ML sway, AP sway, sway area for all parameters (LX, LY, area sway). Furthermore, we showed a significant direction stance x gender for ML sway and direction stance x vision

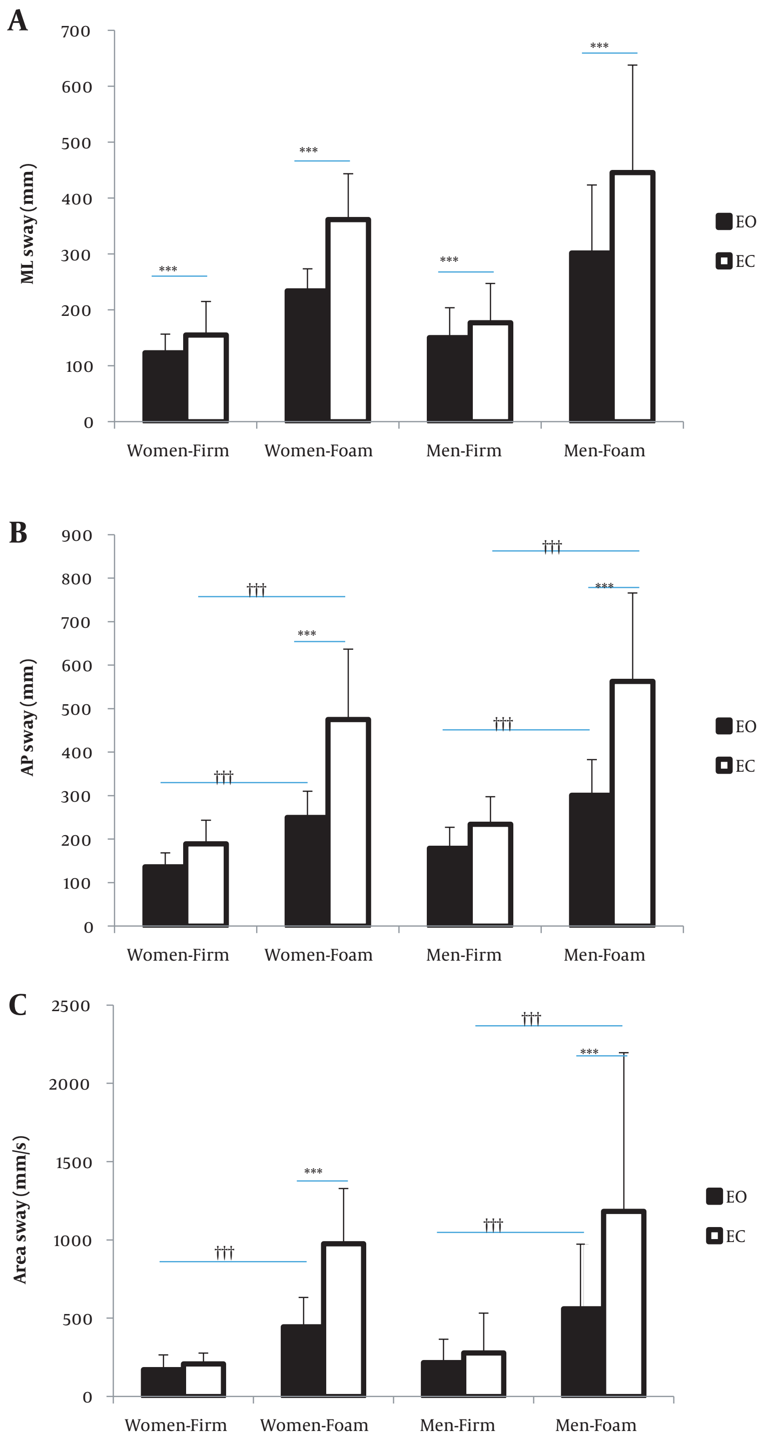

Figure 1. Comparison of CoP parameters between Women-Firm, Women-Foam, Men-Firm, and Men-Foamin firm and foam surface stance and under eyes opened (EO) and eyes closed (EC) condition for CoP parameters: ML sway (A), AP sway (B), Area sway (C). *** $P < 0.001$ between EO and EC condition. ††† $P < 0.001$ between firm and foam surface stance. The values of CoP parameters are expressed as means ± SD.

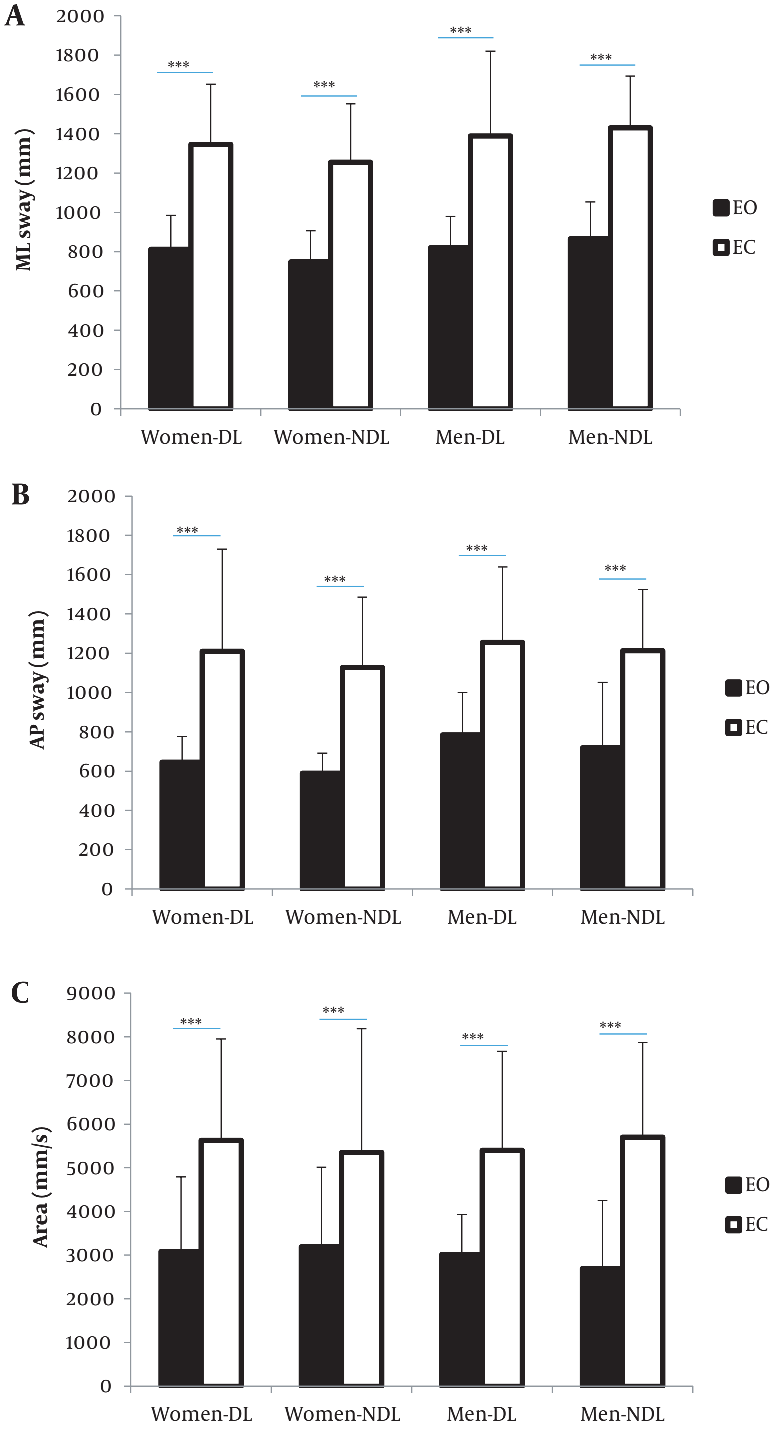

Figure 2. Comparison of CoP parameters between Women-DL, Women-NDL, Men-DL, and Men-ND in dominant leg stance (DL) and non-dominant leg stance (NDL) and under eyes opened (EO) and eyes closed (EC) condition for CoP parameters: ML sway (A), AP sway (B), Area sway (C). *** $P < 0.001$ between EO and EC conditions. The values of CoP parameters are expressed as means ± SD.

interaction for ML sway and AP sway (Table 2). Post hoc analysis showed ML sway (Figure 3A), AP sway (Figure 3B), and sway area (Figure 3C) increased more significantly ($P < 0.001$) without vision in comparison with EO for AP and ML direction stance for both genders.

In addition, ML sway (Figure 3A) was significantly higher in Dyn-AP direction stance than Dyn-ML direction stance for men under EO ($P < 0.001$) and EC condition ($P < 0.001$) for both genders

AP sway (Figure 3B) was significantly higher in Dyn-ML direction stance than Dyn-AP direction stance for men under EO ($P < 0.001$) and EC condition ($P < 0.001$) (Dyn-ML-EO vs. Dyn-AP-EO, $P < 0.001$, Dyn-ML-EC vs. Dyn-AP-EC; $P < 0.001$) and for women under EC condition only ($P < 0.001$). Furthermore, concerning a main effect of gender, ML sway (Figure 3A) and sway area (Figure 3C) were significantly lower for women than men under Dyn-ML-EC condition ($P < 0.01$).

5. Discussion

The objective of our study was threefold: (i) to interpretate the impact of gender, the surface condition, and vision on postural sway; (ii) to assess the impact of gender and vision on the limb symmetry postural sway; and (iii) to understand if the alterations to the dynamic postural sway are depended on gender, directional stance and vision. We hypothesised that females would have better balance sway than males; postural stance would be altered when the base of support is changed or reduced; and postural sway would increase without visual information.

Our main results were: (i) both the surface type and vision significantly affected bipedal postural sway. (ii) a symmetric function was observed between the dominant and non-dominant legs for all parameters sway. (iii) all postural sways were increased when vision was removed for both direction stance (AP and ML). For ML sway, AP direction stance was more stable than ML direction stance for both genders. For AP sway, ML direction stance was more stable than AP direction stance for both genders. In addition, women are more significantly stable than men for only ML direction stance.

5.1. Bipedal Stance

The present study showed that surface type and vision significantly affected bipedal postural sway. Foam surface perturbs balance control more than a firm surface under EO and EC conditions for both genders. Similarly to our result, standing on soft foam surfaces affects more the input to the mechanoreceptors on the soles of the feet, than on firm foam surfaces (18).

Foam blocks were used to investigate postural stability during standing (19-21), or during gait (22-24) and it was assumed that postural stability is affected by the mechanical properties of the compliant surface (22, 25). The present findings support previous study suggested that standing on foam could be at the origin of a decreased ability to accurately detect pressure distribution and body orientation (18, 24) and because of the visco-elastic nature of foam blocks, a reduced ability to exert rigorous, corrective responses could be observed (22, 25).

5.2. Unipedal Postural Stance

The present study aimed to assess the gender differences and differences between the dominant and non-dominant legs throughout static balance tasks in healthy individuals. The results mainly showed that a functional conformity exists between the dominant and non-dominant legs for all parameters sway. The present findings are significant, in fact results could be used to evaluate rehabilitation findings and postural balance deficits. Our outcome align with the recent research that has indicated a functional symmetry exists between the dominant and non-dominant leg balance performance in healthy subjects (26, 27).

In this study, we found that balance control symmetries among both legs can be associated with the physical activity patterns. Daily activities which uses essentially lower body such as walking, climbing stairs, and sweeping the floor represents an integrated part of everyday life. In addition, we did not find any significant differences between men and women for both dominant and non-dominant leg stances. Similarly, to our results, other studies (28, 29) did not found gender-based differences in standing postural control. In contrast to our findings, it was shown that measurements in all directions, indicated (AP and ML directions) that female subjects swayed less than males on either the dominant or the non-dominant leg (7). Also, men have a poorer balance control due to structural and physiological weakness. In fact, men have a more significant moment of body inertia and more strength of their soleus muscles during quiet stance (30).

The present findings could be effective for clinicians and researchers who use comparative evaluations among the limbs to investigate enabling progression in functional exercises and identifying balance issues in hurt person (26).

Investigating the symmetry differences between dominant and non-dominant legs seems necessary. It might give us some information about the balancing behaviors of the balance control system at challenging situations such as single-leg stance. The differences

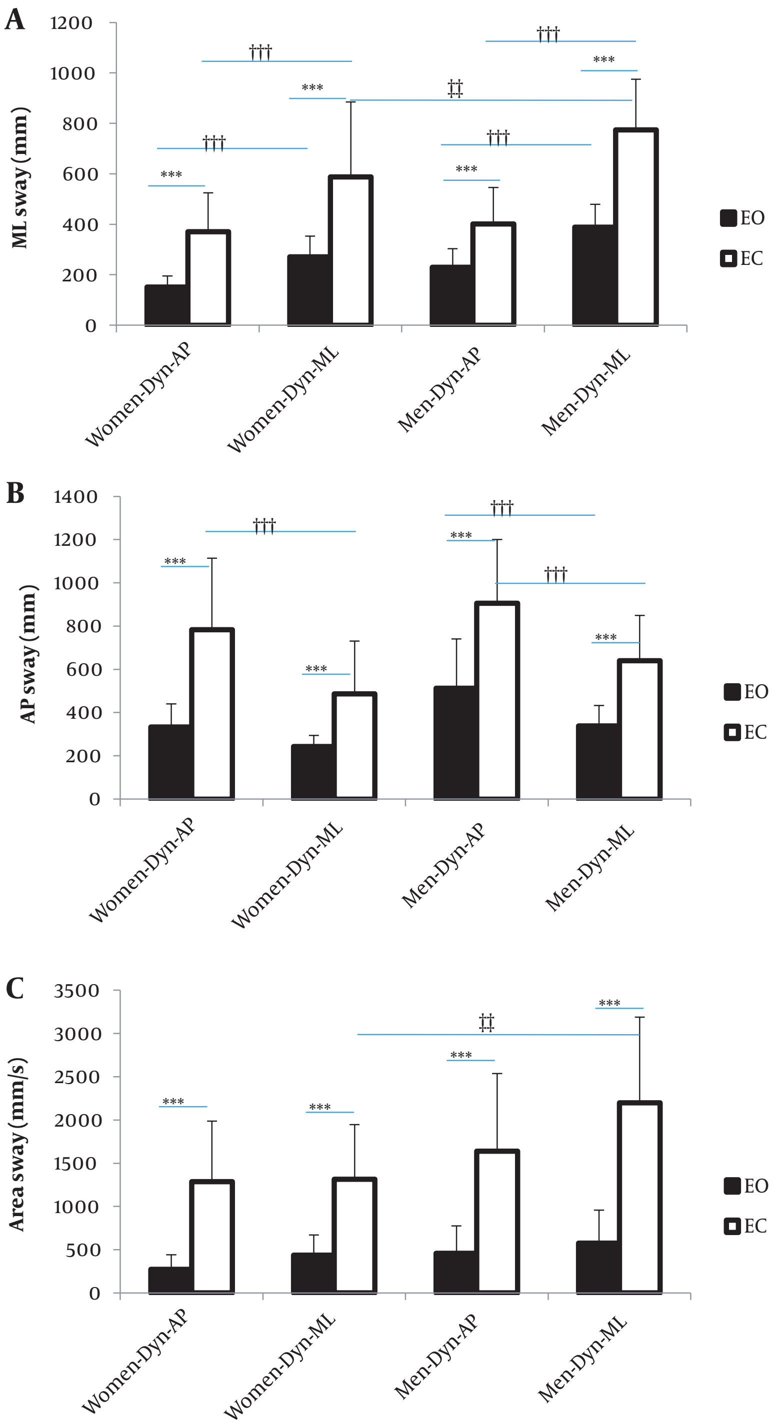

Figure 3. Comparison of CoP parameters between Women-Dyn-AP, Women-Dyn-ML, Men-Dyn-AP, and Men-Dyn-ML in dynamic antero-posterior direction (Dyn-AP) and dynamic medio-lateral direction (Dyn-ML) and under eyes opened (EO) and eyes closed (EC) condition for CoP parameters: ML sway (A), AP sway (B), Area sway (C). *** $P < 0.001$ between EO and EC condition. ††† $P < 0.001$ between Dyn-AP and Dyn-ML direction stance. ‡‡ $P < 0.001$ between women and men condition. The values of CoP parameters are expressed as means ± SD.

between the functionally dominant and non-dominant limbs may help inform clinical decision-making. These results could have a practical implication for clinical intervention after an injury as a common rehabilitation goal following injury is achieving symmetry.

5.3. Dynamic Postural Control

The present study showed that all postural sways increased when vision was removed for both directional stances (AP and ML). For ML sway, AP direction stance was more stable than ML direction stance for both genders. For AP sway, ML direction stance was more stable than AP direction stance for both genders. In addition, women are more stable than men in the ML direction stance. Similar to our finding, Wikstrom et al. (10) has found that females registered higher scores within vertical direction and the composite score on dynamic postural stability. However, no differences between healthy males and females for the time to stabilization have been shown (31).

Females have better dynamic postural stability scores than man. This result could be explained by women's different dynamic postural stability strategies used compared to males (10). In addition, anthropometric parameters could affect stability. In fact, the body height, weight, %BFM and LBM in the studied female population were significantly lower than in men. Therefore, these factors helped women to sway less than men. We used a seesaw to induce dynamic postural control. One of the natural postural challenges of a person standing on a seesaw is to return to a state of balance when there are "large" deviations from it (32). Although the seesaw movement does not resemble all daily activities and sports related to dynamic balance, it does observe angular modification of the ankle.

5.4. Strengths and Limitations

As we know, this study is the first work that investigated the impact of gender, different balance stances, and vision on static and dynamic balance control in healthy individuals. In the purpose of extending our work completed in this observe, future researchers might pursue inspecting the evaluation of the dynamic balance measures among groups of varying ages and populations (eg, athlete vs non-athlete) and apply varying visual, sensory, and vestibular inputs of balance or other dynamic balance devices.

5.5. Conclusions

The present study showed that a foam surface alters postural sway more than a firm surface at a bipedal limb stance and that symmetry exists between dominant and non-dominant limb stances. Furthermore, females have better dynamic balance control than males. Clinicians take the unhurt limb into account to assess the rehabilitation of the injured limb. Our results conclude that it is unnecessary to differentiate between dominant and non-dominant legs for testing. It is important to assess the symmetry difference under dynamic balance control in future studies.

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Footnotes

Authors' Contribution: Study concept and design: A.G and A.B.A.; Analysis and interpretation of data: A.G., S.A., A.B.A., S.J., and A.Y.; Drafting of the manuscript: A.G., S.A., A.B.A., K.W., and M.D., F. M.; Critical revision of the manuscript for important intellectual content: S.G., M.H.E., and B.K., F. M., H. E., and S. B.; Statistical analysis: S.A. and A.B.A..

Conflict of Interests: The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical Approval: All procedures performed in the study involving human participants were in accordance with the ethical standards of national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Informed Consent: Written, informed consent was obtained from all individual participants included in the study.

References

1. Hansson EE, Beckman A, Hakansson A. Effect of vision, proprioception, and the position of the vestibular organ on postural sway. *Acta Otolaryngol*. 2010;**130**(12):1358–63. [PubMed ID: 20632903]. https://doi.org/10.3109/00016489.2010.498024.
2. Patel M, Fransson PA, Lush D, Petersen H, Magnusson M, Johansson R, et al. The effects of foam surface properties on standing body movement. *Acta Otolaryngol*. 2008;**128**(9):952–60. [PubMed ID: 19086193]. https://doi.org/10.1080/00016480701827517.
3. van Dieen JH, van Leeuwen M, Faber GS. Learning to balance on one leg: motor strategy and sensory weighting. *J Neurophysiol*. 2015;**114**(5):2967–82. [PubMed ID: 26400255]. [PubMed Central ID: PMC4737414]. https://doi.org/10.1152/jn.00434.2015.
4. Faraldo-Garcia A, Santos-Perez S, Crujeiras-Casais R, Labella-Caballero T, Soto-Varela A. Influence of age and gender in the sensory analysis of balance control. *Eur Arch Otorhinolaryngol*. 2012;**269**(2):673–7. [PubMed ID: 21789678]. https://doi.org/10.1007/s00405-011-1707-7.

5. Vando S, Haddad M, Masala D, Falese L, Padulo J. Visual feedback training in young karate athletes. *Muscles Ligaments Tendons J*. 2019;**4**(2):137–40. https://doi.org/10.32098/mltj.02.2014.08.
6. Barone R, Macaluso F, Traina M, Leonardi V, Farina F, Di Felice V. Soccer players have a better standing balance in nondominant one-legged stance. *Open Access J Sports Med*. 2010;**2**:1–6. [PubMed ID: 24198563]. [PubMed Central ID: PMC3781875]. https://doi.org/10.2147/OAJSM.S12593.
7. Mutlu C, Recep AÖ, Emre A. Influence of Leg Dominance on Single-Leg Stance Performance During Dynamic Conditions: An Investigation into the Validity of Symmetry Hypothesis for Dynamic Postural Control in Healthy Individuals. *Turk J Phys Med Rehab*. 2014;**60**:22–6.
8. Howell DR, Hanson E, Sugimoto D, Stracciolini A, Meehan 3rd WP. Assessment of the Postural Stability of Female and Male Athletes. *Clin J Sport Med*. 2017;**27**(5):444–9. [PubMed ID: 27428677]. https://doi.org/10.1097/JSM.0000000000000374.
9. Dallinga JM, van der Does HT, Benjaminse A, Lemmink KA. Dynamic postural stability differences between male and female players with and without ankle sprain. *Phys Ther Sport*. 2016;**17**:69–75. [PubMed ID: 26586042]. https://doi.org/10.1016/j.ptsp.2015.05.002.
10. Wikstrom EA, Tillman MD, Kline KJ, Borsa PA. Gender and limb differences in dynamic postural stability during landing. *Clin J Sport Med*. 2006;**16**(4):311–5. [PubMed ID: 16858214]. https://doi.org/10.1097/00042752-200607000-00005.
11. Cug M, Wikstrom EA, Golshaei B, Kirazci S. The Effects of Sex, Limb Dominance, and Soccer Participation on Knee Proprioception and Dynamic Postural Control. *J Sport Rehabil*. 2016;**25**(1):31–9. [PubMed ID: 26355541]. https://doi.org/10.1123/jsr.2014-0250.
12. Dorneles PP, Pranke GI, Mota CB. [Comparison of postural balance between female and male adolescents]. *Fisioterapia e Pesquisa*. 2013;**20**(3):210–4. Portuguese. https://doi.org/10.1590/s1809-29502013000300003.
13. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;**47**(3):339–57. [PubMed ID: 22892416]. [PubMed Central ID: PMC3392165]. https://doi.org/10.4085/1062-6050-47.3.08.
14. Ghram A, Damak M, Costa PB. Effect of acute contract-relax proprioceptive neuromuscular facilitation stretching on static balance in healthy men. *Sci Sports*. 2017;**32**(1):e1–7. https://doi.org/10.1016/j.scispo.2016.06.005.
15. Ghram A, Young JD, Soori R, Behm DG. Unilateral Knee and Ankle Joint Fatigue Induce Similar Impairment to Bipedal Balance in Judo Athletes. *J Hum Kinet*. 2019;**66**:7–18. [PubMed ID: 30988836]. [PubMed Central ID: PMC6458584]. https://doi.org/10.2478/hukin-2018-0063.
16. Hof AL, Gazendam MG, Sinke WE. The condition for dynamic stability. *J Biomech*. 2005;**38**(1):1–8. [PubMed ID: 15519333]. https://doi.org/10.1016/j.jbiomech.2004.03.025.
17. Gouwanda D, Gopalai AA. Investigating Human Balance and Postural Control During Bilateral Stance on BOSU Balance Trainer. *J Med Biol Eng*. 2017;**37**(4):484–91. https://doi.org/10.1007/s40846-017-0282-9.
18. Wu G, Chiang JH. The significance of somatosensory stimulations to the human foot in the control of postural reflexes. *Exp Brain Res*. 1997;**114**(1):163–9. [PubMed ID: 9125462]. https://doi.org/10.1007/pl00005616.
19. Backlund Wasling H, Norrsell U, Gothner K, Olausson H. Tactile directional sensitivity and postural control. *Exp Brain Res*. 2005;**166**(2):147–56. [PubMed ID: 16143860]. https://doi.org/10.1007/s00221-005-2343-5.
20. Riemann BL, Myers JB, Lephart SM. Comparison of the ankle, knee, hip, and trunk corrective action shown during single-leg stance on firm, foam, and multiaxial surfaces. *Arch Phys Med Rehabil*. 2003;**84**(1):90–5. [PubMed ID: 12589627]. https://doi.org/10.1053/apmr.2003.50004.
21. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys Ther*. 1986;**66**(10):1548–50. [PubMed ID: 3763708]. https://doi.org/10.1093/ptj/66.10.1548.
22. MacLellan MJ, Patla AE. Adaptations of walking pattern on a compliant surface to regulate dynamic stability. *Exp Brain Res*. 2006;**173**(3):521–30. [PubMed ID: 16491406]. https://doi.org/10.1007/s00221-006-0399-5.
23. Stefanyshyn DJ; Nurse; Hulliger; Wakeling; Nigg. Changing the texture of footwear can alter gait patterns. *J Electromyogr Kinesiol*. 2005;**15**(5):496–506. https://doi.org/10.1016/j.jelekin.2004.12.003.
24. Perry SD, McIlroy WE, Maki BE. The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. *Brain Res*. 2000;**877**(2):401–6. https://doi.org/10.1016/s0006-8993(00)02712-8.
25. Horak FB, Hlavacka F. Somatosensory loss increases vestibulospinal sensitivity. *J Neurophysiol*. 2001;**86**(2):575–85. [PubMed ID: 11495933]. https://doi.org/10.1152/jn.2001.86.2.575.
26. Alonso AC, Brech GC, Bourquin AM, Greve JM. The influence of lower-limb dominance on postural balance. *Sao Paulo Med J*. 2011;**129**(6):410–3. [PubMed ID: 22249797]. https://doi.org/10.1590/s1516-31802011000600007.
27. Clifford AM, Holder-Powell H. Postural control in healthy individuals. *Clin Biomech (Bristol, Avon)*. 2010;**25**(6):546–51. [PubMed ID: 20462678]. https://doi.org/10.1016/j.clinbiomech.2010.03.005.
28. Ekdahl C, Jarnlo GB, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. *Scand J Rehabil Med*. 1989;**21**(4):187–95.
29. Hahn T, Foldspang A, Vestergaard E, Ingemann-Hansen T. One-leg standing balance and sports activity. *Scand J Med Sci Sports*. 1999;**9**(1):15–8. [PubMed ID: 9974192]. https://doi.org/10.1111/j.1600-0838.1999.tb00201.x.
30. Farenc I, Rougier P, Berger L. The influence of gender and body characteristics on upright stance. *Ann Hum Biol*. 2003;**30**(3):279–94. [PubMed ID: 12850961]. https://doi.org/10.1080/0301446031000068842.
31. Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop Relat Res*. 2002;(401):162–9. [PubMed ID: 12151893]. https://doi.org/10.1097/00003086-200208000-00019.
32. Gugayev KV, Kruchinin PA, Formalskii AM. A model of maintaining balance by a person on the seesaw. *J Appl Math Mech*. 2016;**80**(4):316–23. https://doi.org/10.1016/j.jappmathmech.2016.09.006.