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Influence of feet's position on maximum forward lean using a new estimate of functional balance

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Functional stability is crucial to the daily activity of an independent person. Functional balance testing is widely used in laboratories and has proven to be a reliable indicator of fall risk. So far, only few studies have paid attention to the impact of foot positioning on the results of functional balance measurements. Thirty healthy adults took part in experiment. LOS test was performed for four stance positions: preferred width, wide stance (feet parallel, 28 cm apart), narrow stance (feet together) and angle stance (heels together, toes pointing outside, 90° angle between them) with eyes opened and closed. The results of the study show significant differences between angle and narrow stance according to wide and preferred width stances – angle and narrow positions didn't allow participants to lean as far as other positions. Vision had stabilizing influence on maximum forward lean in all tested positions.

Key words: *limits of stability test, maximum forward lean, body balance*

1. Introduction

Maintaining an upright body posture is considered crucial in everyday life and thus constantly attracts scientific interest. Although the activity of maintaining a stable posture is spontaneous and mostly is not subjected to conscious control, it is a complex process [38].

Many methods has been developed to date that make it possible to investigate one's stability. These investigations can be conducted using static postures (quiet standing) or more functional tasks like functional reach test [7].

Functional tests can be performed in clinical settings without any specialized equipment or with the use of computerized posturography. The latter is considered to be reliable method for balance function testing [11], [12]. One of the most common procedures of functional testing is the measure of the limits of stability (LOS) where participants are asked to lean in different directions while standing on a force plate. Studies proved the LOS test to be reliable examination of one's functional balance [18], [24]. LOS test has been used to provide measures of functional stability in different populations – older adults [4]–[6], [27] adults [17], [28] and young adults [24].

Although the procedure of the LOS test has been well described in the literature in many studies, one can observe many discrepancies concerning the feet placement during the test. There are studies that follow standardized feet position recommended by the manufacturers of the equipment [4]–[6], [31]. Some studies suggest to practice a comfortable position chosen by participant [9], [15], [16], [23], but some of them impose a narrow [1], hip width apart [24], or shoulder width apart stance [13]. There are also studies that determined the foot placement very precisely [8], [32], e.g., heels 25 cm apart, feet angled 8° [33] or heels 12 cm apart, feet angled 15° [17]. The International Society of Posturography (ISP) also recommended position of the feet during force plate measurements where participants should stand barefoot on the platform with the heels together, at an angle of 30 degrees between the medial sides of the feet [19], but this orientation is not widely used in papers. Unfortunately, many authors did not specify feet's positioning

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on a platform in theirs studies. It seems to be intuitive that feet placement during the balance measurement should reflect the most comfortable position for the participant. McIlroy and Maki [26] tried to average preferred foot position to facilitate close generalization between participants and studies. They estimated that the average preferred foot position is 0.17 m between heel centres, with an angle of 14° between the long axes of the feet. They also stated that the existing standards are not congruent with the preferred ones.

It has been already well documented that different feet position can affect body sway in quiet standing [20], [22], [25], [35]. For example, a narrow feet positioning causes an increase of the sway path, the sway area and the range of the lateral sway. Most of the authors recommend feet position with heels 10 cm apart and feet collaterally [20], [25], [35] or participant's preferred position [22]. So far, only one study estimated the influence of feet positioning on the functional balance test [22]. The authors used five different feet positions in their research during static and functional tests. The functional test (LOS) was conducted in eight directions without feedback in continuous manner. Although the study has its merits, we believe that more thorough analysis of feet position with regard to the functional balance testing is needed. According to the recent literature, the test employed for functional testing in the Krewer's study [22] does not fully reflect the functional capabilities of the participant [32].

The aim of the present study was to determine good feet positions for testing maximum forward lean (LOS test). Based on literature review, we hypothesized that different positioning of the feet during LOS test has an influence on maximum forward lean and that certain placement of the feet might distort the actual functional capabilities of the participant. We suspected that narrow stances, with smaller base of support won't allow participants to perform as good as wider stances, which suggests that the feet placement is crucial for valid estimate of functional balance. We also hypothesized that the lack of visual feedback (closed eyes) has another detrimental influence on the functional maximum forward lean together with the change of the shape of the base of support.

2. Materials and methods

Material

The study was conducted on 30 young, healthy adults (15 women and 15 men) aged between 19–26 years (average 23 ± 2). Inclusion criteria were age of 20–25 years and disposition during testing. Exclusion criteria were injuries of lower limbs or any balance disorders. The participants gave a written informed consent for voluntary participation in this study. The research was accepted by the ethics committee.

Previous studies showed that in young adults (age of 21–35) posturographic studies can be done without gender division consideration [21]. Our initial analysis also showed no differences between men and women with respect to the experimental data, therefore the further analysis was conducted collectively on men and women.

Procedures

The study comprised anthropometric foot measurements and LOS test procedure. Anthropometric measurements of the foot included: foot length, hallux length, forefoot length and length of hind foot. Foot measurements were used to calculate Forward Functional Stability Indicator (FFSI) [32].

Next, participants performed 3 consecutive trials of maximal voluntary forward leaning (LOS test) in 4 different feet configurations: 1) participant's preferred width position open stance – feet parallel, 2) feet 28 cm apart, 3) narrow stance – feet together and 4) angle stance – heels together, toes pointing outside, 90° angle (calculated between the lines joining the center of the heel and hallux [26] between left and right (Fig. 1). The four foot position was performed in a random order. Participants were instructed to step off the platform between trial and rest in order to avoid fatigue or boredom. Participants performed trials with eyes opened (EO) and then repeated them with eyes closed (EC).

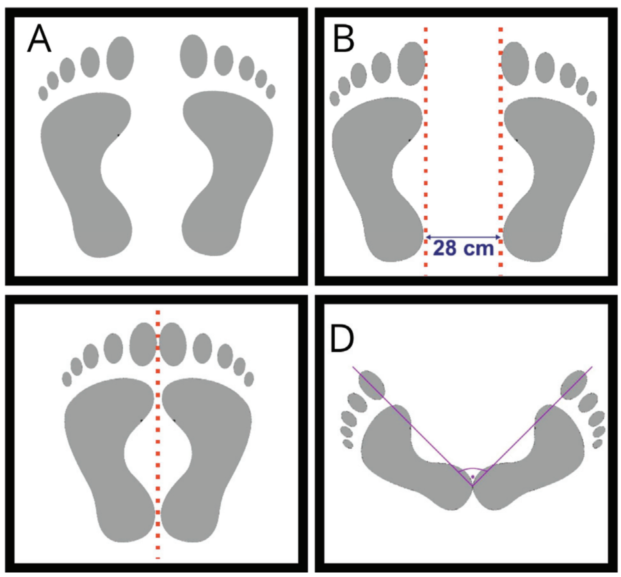

Fig. 1. Feet configuration on the platform – preferred width (A), wide (B), narrow (C) and angle (D) stances

The employed LOS test procedure consisted of three distinct phases and lasted 30 sec: 1) quiet standing – participants were standing still for 10 seconds on the platform with arms along the trunk's sides, looking straight ahead, 2) leaning forward as fast and as far as they could without losing contact of the heels with the platform, 3) maintaining inclined position for the rest of the trial (about 15 sec). Participants were instructed that hips shouldn't be moving backwards, movement could only be generated in ankle joints. The same procedure was performed for the trials with EC.

Equipment

All functional balance investigations were taken with the use of force platform (AMTI, Accugait, Watertown, MA, USA) where forces (F_x, F_y, F_z) and moments of force (M_x, M_y, M_z) were registered at 100 Hz. The anthropometric measurements were taken with the use of the spreading caliper.

Data processing

The raw platform data were subject to further process using the Matlab (Mathworks, Natick, MA, USA). A 4th order low-pass Butterworth filter with a sampling frequency of 7 Hz was applied during raw data processing. The following calculated parameters were further analyzed: mean COP trajectory during first (quiet standing) and third (inclined position) phase with respect to the point of the vertical projection of the medial malleolus, mean velocity of COP in first (phase 1) and third phase (phase 3) of the LOS test, Forward Functional Stability Indicator (FFSI), calculated with the following formula [32]:

$$\text{FFSI [\%]} = \text{NMVE/FFL} \times 100,$$

where FFL is the length of the forefoot [cm] and NMVE (normalised maximal voluntary excursion) is the range of displacements [cm] of COP (between minimum and maximum) during third phase (inclined position) in AP plane.

Statistical analysis

The basic parameters of descriptive statistics were calculated. Normal data distribution was tested with the Shapiro–Wilk test. A Friedman test was carried out to compare balance parameters between four conditions. Wilcoxon signed-rank test was used to determine whether vision (Eyes Open – EO or Eyes Close – EC) had significant influence on mean COP trajectory and FFSI in different testing conditions. Kendall's coefficient of concordance (W) were used as the estimate of effect size for Friedman test. For Wilcoxon signed-rank test, effect size was calculated with the formula $r = Z/\sqrt{N}$, proposed by [30]. The significance level was assumed for $p < 0.05$. For all the calculations, the Statistica software v.13.3 with the Plus Software Package was used.

3. Results

First, the differences between standing conditions for mean COP trajectory in the first and the third phase was calculated using a non-parametric Friedman test for repeated measures. The calculations were done separately for EO and EC. There were significant differences between standing conditions in the first phase and the third phase of the LOS test for EO and EC. The Friedman test conducted for EO condition rendered a significant chi-squares which were $\chi^2(3) = 54.5$, $p < 0.001$ $W = 0.60$ for mean COP trajectory in first phase, and $\chi^2(3) = 55.9$, $p < 0.001$ $W = 0.62$ for mean COP trajectory in third phase. Similarly, the Friedman test rendered significant chi-squares for EC condition which were $\chi^2(3) = 56.1$, $p > 0.001$ $W = 0.62$ and $\chi^2(3) = 66.3$, $p < 0.001$, $W = 0.74$ for mean COP trajectory in first phase and mean COP trajectory in third phase, respectively. Post-hoc analysis revealed further detailed differences between conditions (Fig. 2).

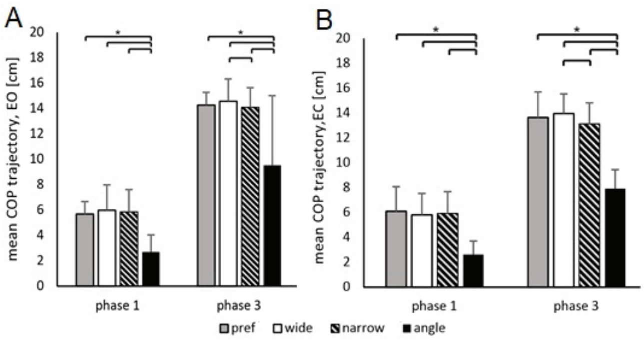

Fig. 2. Median results ± SD of mean COP trajectory, A) eyes opened and B) eyes closed *significant differences are marked at $p < 0.05$

Second, sway velocity of COP was subjected to Fridman's test with respect to the feet alignments. There were significant differences between standing conditions in the first phase and the third phase of the sway velocity. The rendered chi-square was $\chi^2(3) = 42.8$, $p = 0.00$ $W = 0.48$. Post-hoc analysis revealed further detailed differences between conditions (Fig. 3).

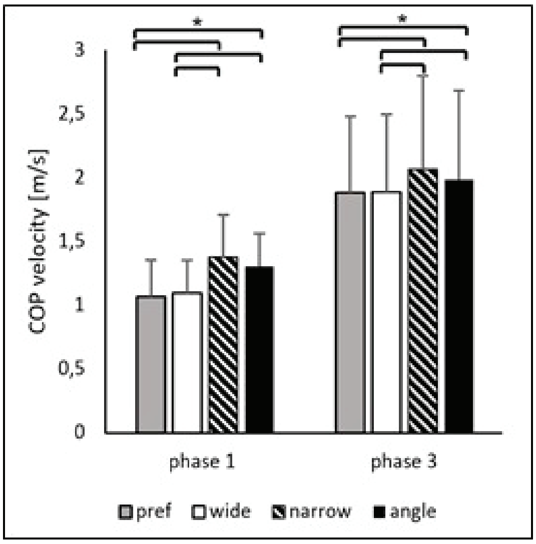

Fig. 3. Velocity values of COP (median ± SD) for the first and third phase of the LOS test in different feet placement conditions *significant differences are marked at $p < 0.05$

The Friedman test conducted for FFSI in different stance conditions rendered significant chi-square both for EO and EC and equaled $\chi^2(3) = 42.8$, $p < 0.001$ $W = 0.48$, respectively, in the first phase of the LOS test and for EC and EO $\chi^2(3) = 56.2$, $p < 0.001$, $W = 0.62$, $\chi^2(3) = 66.3$, $p < 0.001$, $W = 0.74$ respectively in the third phase of the LOS test. Post-hoc analysis revealed further detailed differences between conditions (Fig. 4). Interestingly, in the angle stance, participants reached only 70.6% (EO) or 58.2% (EC) of their Forward Functional Stability Region [32] while in other positions, they achieved about 100%, wide stance allowed participants to lean by 4% further than narrow stance with EO and by 7 % – with EC.

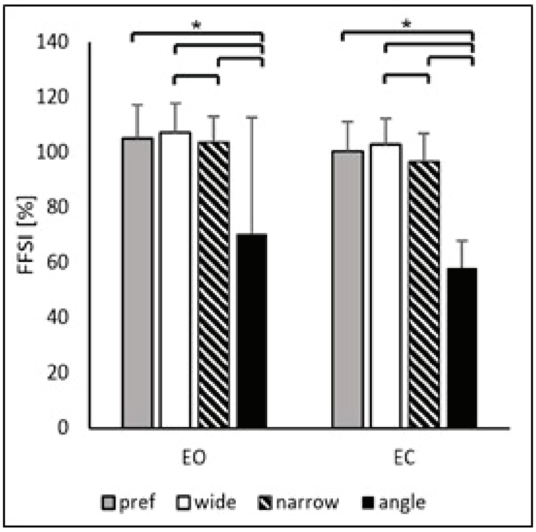

Fig. 4. Median results ± SD of Forward Functional Stability Indicator *significant differences are marked at $p < 0.05$

Finally, to determine the influence vision on maximum forward lean, mean trajectory of COP and FFSI was compared between EO and EC conditions in each feet standing position. A Wilcoxon signed-ranks test showed statistically significant differences in the first and third phase of the LOS test. With EO, participants' COP projection was significantly more anterior with respect to the EC condition in first phase only in preferred width feet position and in all four positions during third phase ($p < 0.001$) (Fig. 5). Effect size total $r = 0.54$ for preferred width position in first phase and $r = 0.6$ for preferred width, $r = 0.63$ for wide, $r = 0.82$ and $r = 0.74$ for angle position in third phase. Similar analysis for FFSI the same significant differences between the EO and EC conditions ($p < 0.001$) (Fig. 5). Effect size total $r = 0.61$ for preferred width, $r = 0.63$ for wide, $r = 0.82$ and $r = 0.75$ for angle position.

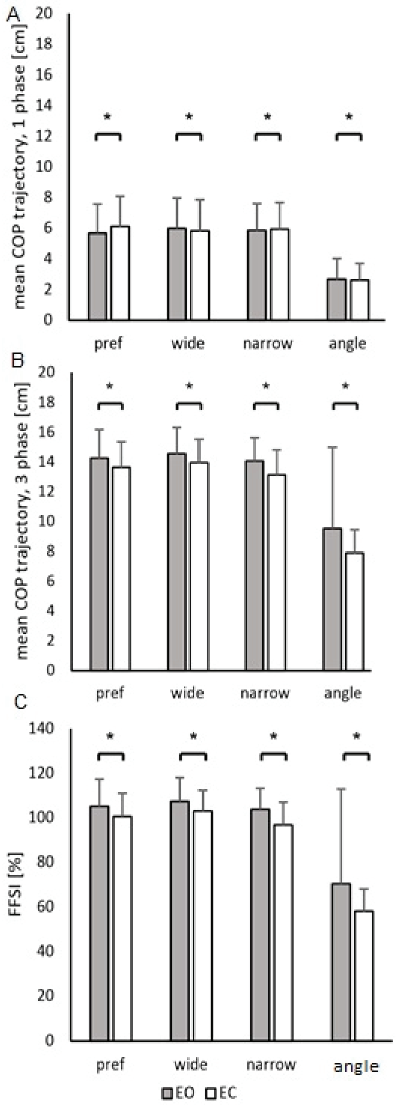

Fig. 5. Median results ± SD of COP trajectory in first phase (A), third phase (B) and FFSI (C) *significant differences are marked at $p < 0.05$

4. Discussion

Most common positions of the feet during balance assessment that can be found in literature are preferred or natural stance [9], [15], [16], [23] – as our studies show this is a position that allows participants to achieve good balance performance. Our first hypothesis was that different positioning of the feet during LOS test has an influence on maximum forward lean and that certain placement of the feet might distort the actual functional capabilities of the participant. The results only partially confirmed the assumption. Only in angle feet position participants achieved significantly smaller forward leaning result, which may be a result of shortening of base of support in AP plane. Surprisingly, when the participants were standing in a narrow stance (feet together) they did not perform drastically worse than in other conditions and the results were similar to those achieved in preferred width stance. Although it is commonly accepted that narrow stance provides smaller base of support there were only few significant differences between narrow and wide stance (mean COP trajectory during 3 phase, COP velocity, FFSI). Supposedly narrow stance causes higher tension in postural muscles [14], which might effect in better maximum forward lean performance.

Upright standing in most previous studies has primarily been examined in the side-by-side position in which the lower limbs are aligned in parallel about hip or shoulder width apart. Fewer studies investigated an angle between the feet and its influence on the postural characteristics. An early study by Kirby et al. [20] reported significant influence of the foot position on postural sway and the mean position of the center of pressure. In their study, parallel standing as well as different foot angle variations were examined. In our study the participants mean COP position in angle foot placement was significantly smaller than in any other standing conditions. Similar tendency was observed in [20]. In the study by Uimonen et al. [35] we can find results similar to ours, confirming that narrow stance elicit substantial increase in postural sway velocity. From the motor control perspective this tendency is not optimal and leads to greater metabolic expenditure. Therefore, this feet position is rarely chosen by the participants as more demanding or difficult and is in accordance with a general assumption that a broad stance condition improves medio-lateral postural control [36]–[38]. There are several papers addressing the feet positioning during quiet standing, but research relating the feet positioning to functional balance tests are scarce. In a recent study Krewer et al. [22] addressed the problem of foot positioning in dynamic (functional) balance testing. They examined only the stance width on the static and dynamic balance. Their results are in accordance with our study where the wider stance elicits the best performance in functional balance. Additionally, our results show detrimental influence of the angle stance on the AP functional balance, where in the angle foot position, the results were the smallest. Natural feet positioning could be optimal for testing diverse groups, for example in the situation when the tested group consists of tall and short participants, while determined, identical position feels different to them. Short participants could consider 10 cm to be a wide position as their natural, but for taller participants this could be their narrow position.

Although, angle stance is recommended by ISP [19], it does not provide optimal conditions for balance perform. Therefore, one should consider to place the feet parallel to each other in order to avoid the detrimental influence of the angle foot placement, especially in the functional balance testing. Also, in quiet standing, position with toes pointing outside is not as stable as when feet are parallel [35]. Probably diagonal position of feet makes use of the big toe not as efficient as when it is aligned [3]. Forward lean in this position may transfer pressure to the medial side of the feet and prevent from proper use of intrinsic muscles of the feet. Restrictions caused by this positioning could be a subject of follow up studies.

The biggest problem with preferred width feet positioning might be the repeatability – researchers need to mark footprints on the platform to enable participants to stand at the same spot during all the attempts. This problem can be also mitigated when the results are related to standardized foot measures [32].

Our second hypothesis was that the lack of visual feedback (closed eyes) worsens functional maximum forward lean together with the change of the shape of the base of support. It is noteworthy that this study includes a manipulation of the visual feedback not to make a novel contribution to the literature regarding vision but to capture potentially subtle effects of feet placement on functional stability that may be present only when the eyes are closed or the effect could be amplified. In general, our results are mostly in accordance with those reported in the literature especially when we speak about functional balance [2], [10], [20], [29], [34]. The participants tended to decrease their exposure to the threat by less inclined posture expressed by the mean COP position significantly closer to the mid stance. As expected, this effect was amplified in the more demanding feet placement.

We would like to acknowledge limitations of this study. All of our participants were young and healthy students. There is no guarantee that our results can be related to different groups (e.g., older people or clinical patients). Also, force plate used in this study was narrow – wide position was limited by edges of plate.

5. Conclusions

Feet alignment has an influence on maximum forward lean. Although participants achieved different results in tested positions, significant differences were found between angle and narrow stances and between preferred width and wide stances. A lack of significant differences between preferred width and wide stances indicates that they could be successfully used during LOS test. The worst alignment seems to be angle stance – participants showed smaller range of lean and used less of their functional support plane than in other positions. This conclusion can be transferred into training programs – since angle and narrow stances are more challenging to keep balance, they can be used in next steps as the program progresses. Since there were no significant differences between preferred or wide stances, there is no need to enforce determined positions because participants choose the best one.

Vision also has an influence on maximum forward lean. In all four positions, participants performed better with eyes opened (they leaned further and used more % of functional stability indicator).

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