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Original Article

The effects of toe-out and toe-in postures on static & dynamic balance, risk of fall and TUG score in healthy adults

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ABSTRACT

Background: Toe-in and toe-out foot positions have not yet been tested for dynamic balance and risk of fall. The aim of this study was to investigate the effects of these two modifications on static and dynamic postural stability and risk of fall through instrumental (Biodex Balance System®) and functional (timed up and go-TUG test) tools.
Methodology: Twenty healthy adults (8 males, 12 females, age: 29 ± 4.10 years, BMI: 21.56 ± 2.36 kg/m^2) participated in this study. Static and dynamic (levels 8 and 2) balance with single stance and double stance and dynamic (level 8 and levels 6–2) for risk of fall with double stance were tested with the Biodex Balance System with three self-selected feet positions: straight (13.8°), toe-out (35.6°) and toe-in (−11.9°) for each test condition. Additionally, TUG test was performed with toe-out and toe-in gait.
Results: The results of repeated measures ANOVA showed significant differences ($p < 0.05$) between straight and modified toe angles in balance at dynamic level 2 with both double and single stance conditions. Significant differences ($p < 0.001$) were also found in TUG scores for the test conditions.
Conclusion: Toe-in and toe-out gait modifications have significant effects on balance at higher levels of platform tilt and functional balance. Further investigations with knee osteoarthritis patients and electromyography may provide insight in balancing strategies adopted by the body in toe-out and toe-in gait.

1. Introduction

It is crucial in performing Activities of Daily Living (ADLs) that one maintains their static and dynamic balance. The postural stability which is defined as a person's control over their body's orientation in space is compromised if proper balance is not maintained. Decreased postural stability makes an individual vulnerable to perturbations and thus increases the risk of falling over. Falls have emerged as a major health concern especially in older adults [1–3]. It is estimated that 11% of falls in older adults result in fatalities [4]. Falling over is also reported to have a major contribution in injury-related hospitalization in different parts of the world [5–8].

Biomechanics defines stability in terms of the conscious and subconscious shifting of the body's centre of mass (CoM) through swaying the body or changing the foot position [9]. If this CoM shifts out of the base of support, the individual tends to return it to this area. Since the Centre of Pressure (CoP) is the representative point of average distribution of the pressure over the entire contact area, its excursion over this area can represent the balance of a person [3,10]. There is a wide range of tools used to assess postural stability and balance of a person. Functional tools such as timed up and go test (TUG) [11], step test [12], and star excursion balance test (SEBT) [13] aim to measure stability by observational recording. While instrumental tools such as Biodex Balance System (BBS; Biodex Medical System Inc., Shirley, NY, USA) [14] and Balance Master- NeuroCom (BalanceMaster®, NeuroCom International Inc., Oregon) [15] provide digital measures of postural stability and risk of fall derived through CoP excursion.

Altering the foot progression angle, defined as the angle between the line joining the centre of the ankle joint to the second metatarsal head and the progression axis of the walk, has been observed to shift the CoP mediolaterally [16]. This shifting reduces the moment arm of the ground reaction force, in result decreasing the knee adduction moment (a widely acknowledged measure of the knee joint load) [16]. There can be two types of deviations in the natural foot progression angle during gait: (1) toe-out gait: shifting the foot externally while walking (2) toe-in gait: shifting the foot internally while walking. These two gait modifications have been focused as treatment techniques for knee load dependent disorders such as medial knee osteoarthritis.

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So far, studies have reported the effects of changing foot position on balance in quiet standing with double stance and single stance. The variations in foot position include changing the heel width (inter-calcaneal distance), the angle between the feet and anteroposterior or mediolateral position of the feet relative to each other [17–20]. In real-life, however, there are situations where a person must encounter uneven terrains (pebbles, gravels etc.), ramps, stairs and slippery or wet floor on which the person must regain balance. To the best of our knowledge, the effects of changing foot progression angle while standing on an unstable platform with varying degrees of tilt have not been observed. Toe-in and toe-out gait modifications are gaining popularity as rehabilitative strategies for medial knee osteoarthritis and other lower limb disorders related to knee joint load. It has been reported that knee osteoarthritis patients already have impaired balance and increased the risk of fall as compared to healthy individuals [21]. Therefore, it is important to investigate if toe-in or toe-out gait compromise the postural stability of the patient and/or increase the risk of fall. If such findings are discovered, then these gait modifications need to be prescribed with caution.

This study aims to investigate the effects of toe-out and toe-in foot positions on Overall Stability Index (OSI), Medial-Lateral Stability Index (MLSI) and Anterior-Posterior Stability Index (APSI) by using BBS. To investigate further, the study aims to use a functional tool (TUG test) in observing the effects of toe-in and toe-out gait on balance. It is hypothesized that toe-in and toe-out foot positions will affect the postural stability and risk of fall of healthy individuals.

2. Methods

2.1. Participants

Twenty healthy participants (8 males, 12 females) were recruited for this study through community advertisement and the word of mouth. The anthropometric data of the sample is provided in Table 1.

The study was conducted at the Department of Biomedical Engineering, University of Malaya and the participants were undergraduate and post-graduate students. The population under consideration contained individuals from several ethnic backgrounds (Malay, Chinese, Tamil, foreigners including African, Iranian, Bengali, Indian and Pakistani). The sample was selected keeping in mind this diversity to avoid population bias.

2.2. Inclusion criteria

The inclusion criteria for the subjects included healthy young adults, aged 20–40 years, having a BMI of less than 25 kg/m^2 (non-overweight and non-obese [22]) and having no physical disability. The participants were excluded based on any neurological or musculoskeletal disorder or inability to adopt novel gait pattern.

2.3. Ethical approval

Approval was obtained from the University of Malaya Research Ethics Committee (UM.TNC2/RC/H&E/UMREC — 132). All participants provided written informed consent for the study.

Table 1
Anthropometric data of the sample taken.

	Mean	SD
Age (years)	29	4.106
Weight (kg)	59.3125	10.375
Height (m)	1.655125	0.114
BMI (kg/m^2)	21.56788	2.361

2.4. Sample size

The sample size for this study was calculated using an F-test statistical design for repeated measures (within effects), having an effect size of 0.25 [23], a power of 80%, and an alpha error of 5%, suggesting at least 20 participants for this study.

2.5. Equipment and settings

The Biodex Balance System (BBS), contains a circular standing platform that measures a person's postural stability through the shift in the centre of pressure (CoP). The platform is unstable (with up to 20° tilt in the 360° range of motion) and collects data with a sampling frequency of 20 Hz. The platform can move in anterior-posterior (AP) and medial-lateral (ML) axes simultaneously, giving three types of measurements: Anterior/Posterior Stability Index (APSI), Medial/Lateral Stability Index (MLSI) and Overall Stability Index (OSI). A higher control over balance is indicated by a lower MLSI, APSI or OSI score. The BBS has shown reliability estimates (R) of 0.92, 0.89 and 0.93 for OSI, APSI and MLSI respectively [24].

$$MLSI = \sqrt{\frac{\sum (0 - X)^2}{No.\ of\ Samples}}$$

$$APSI = \sqrt{\frac{\sum (0 - Y)^2}{No.\ of\ Samples}}$$

$$OSI = \sqrt{\frac{\sum (0 - X)^2 + \sum (0 - Y)^2}{No.\ of\ samples}}$$

At the centre of balance (the position at which the participant is standing balanced, represented by the dot in the middle of the crosshair on screen), the x and y variables are (0,0). As the user deviates from the centre of balance in sagittal plane, the value of x increases, while when they deviate from this centre of balance in frontal plane, the value of y increases. In other words, we can say that x and y represent the co-ordinates of the centre of gravity on the platform, whose values is (0,0) at time $t = 0$. Number of samples is the number of test recordings for each test protocol.

The platform has 12 levels of settings (12: most stable platform and 1: most unstable platform). For this study, the following set of platform settings was used in a random order:

A. Postural stability-for both double stance and single stance

(1) Static
(2) *D8*: Platform setting 8
(3) *D2*: Platform setting 2

B. Risk of fall

(1) *D8*: Platform setting 8
(2) *D6-2*: Starting level 6 to ending level 2. i.e. each test trial starts from a level of 6 and keeps on decreasing to level 2

2.6. Study protocol

The participants were asked to stand on the BBS barefoot with eyes open, facing the monitor. The data were taken with the following protocol: (1) straight toe, **ST** (natural foot position);(2) toe-out, **TO** (maximum external rotation within comfort limits); (3) toe-in. **TI** (maximum internal rotation within comfort limits), see Fig. 1. The participants were instructed to attempt to keep the moving black dot at the centre of the crosshair displayed on the monitor by balancing themselves. Their hands were to be kept on their hips, and the trials were discarded if they supported themselves with handlebars. The BBS

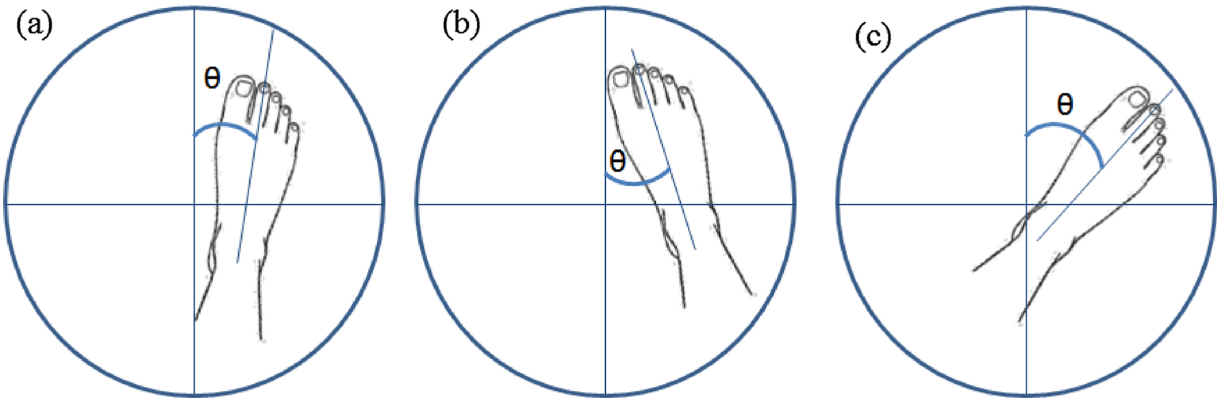

Fig. 1. Toe- positions during BBS and TUG test protocols. (a) Straight toe, (b) toe-in, and (c) toe-out, where θ represents toe angle.

Table 2
Balance and risk of fall indices. Where OSI is Overall Stability Index, APSI is Anterior/Posterior Stability Index, MSLI is Medial/Lateral Stability Index and TUG is timed up and go.

	Straight toe (13.8° ± 4.4°)		Toe-out (35.6° ± 5.0°)		Toe-in (−11.9° ± 4.4°)	
	Mean	SD	Mean	SD	Mean	SD
Postural stability-double stance						
Static						
OSI (°)	0.007189	0.005	0.0087	0.004	0.008858	0.003
APSI (°)	0.004424	0.004	0.0066	0.004	0.006604	0.002
MLSI (°)	0.003744	0.004	0.0040	0.002	0.003227	0.003
D8						
OSI (°)	0.015	0.006	0.017	0.006	0.015	0.003
APSI (°)	0.011	0.003	0.010	0.003	0.011	0.003
MLSI (°)	0.008	0.005	0.012	0.006	0.008	0.002
D2						
OSI (°)	0.038	0.024	0.066	0.018	0.057	0.027
APSI (°)	0.025	0.020	0.050	0.015	0.054	0.017
MLSI (°)	0.019	0.014	0.054	0.021	0.042	0.018
Risk of fall						
D8						
OSI	0.014	0.004	0.011	0.006	0.012	0.004
D6-2						
OSI	0.038	0.034	0.040	0.028	0.046	0.026
Postural stability-single stance						
Static						
OSI (°)	0.023	0.012	0.027	0.015	0.016	0.033
APSI (°)	0.017	0.012	0.016	0.007	0.009	0.016
MLSI (°)	0.012	0.004	0.018	0.016	0.011	0.009
D8						
OSI (°)	0.022	0.012	0.031	0.021	0.019	0.012
APSI (°)	0.011	0.005	0.016	0.006	0.011	0.003
MLSI (°)	0.016	0.014	0.023	0.021	0.014	0.013
D2						
OSI (°)	0.028	0.009	0.116	0.045	0.069	0.020
APSI (°)	0.023	0.012	0.083	0.006	0.052	0.014
MLSI (°)	0.023	0.014	0.078	0.111	0.062	0.017
TUG score						
t (s)	8.046	0.825	9.720	1.408	9.447	0.886298

Where OSI is Overall Stability Index, APSI is Anterior-Posterior Stability Index, MLSI is Medial-Lateral Stability Index, D8 is dynamic setting 8, D2 is dynamic setting 2, D6-2 is dynamic setting 6–2 and TUG is timed-up and go.

platform has angular markings on it that were used to measure the toe angles. Before each trial, it was made sure that the feet (or foot in case of single stance) are placed according to the test condition. The distance between the heels was kept constant at 0.16 m in order to avoid the adaptability effects on the balance due to different heel distances [21]. The participants were asked not to change foot position during the trial recording, despite the movement of the platform. Each participant was trained with walking with toe-out and toe-in gait with adequate practice by the mutual discretion of the participant and the investigator. Static and dynamic tests were obtained for both postural stability and risk of fall with 3 trials of 20 s durations in each type of test, with a rest period of 10 s in between trials. Postural stability test for single limb stance was also conducted with the same protocol. All participants were right-handed and right foot was their dominant foot.

2.7. Timed up and go (TUG) test

The TUG test is considered a reliable measure of the functionality and balance [25,26]. The participants were asked to stand up from a sitting position, walk 3 m at normal walking speed, turn around, walk

Table 3
ANOVA results of OSI for postural stability, the risk of fall and TUG scores.

Test type	Toe-position A	Toe-position B	Mean difference (A–B)	Sig
Postural stability-double stance				
Static	ST	TO	−0.001	0.628
		TI	−0.001	0.693
	TO	ST	0.001	0.628
		TI	0.000	0.913
	TI	ST	0.000	0.693
		TO	0.000	0.913
D8	ST	TO	−0.005	0.616
		TI	−8.625E5	0.985
	TO	ST	0.005	0.616
		TI	0.005	0.554
	TI	ST	8.625E5	0.985
		TO	−0.005	0.554
D2	ST	TO	−0.028[a]	0.020
		TI	−0.019[a]	0.023
	TO	ST	0.028[a]	0.020
		TI	0.009	0.330
	TI	ST	0.019[a]	0.023
		TO	−0.009	0.330
Risk of fall				
D8	ST	TO	−0.001	0.835
		TI	−0.001	0.762
	TO	ST	0.001	0.835
		TI	0.000	0.952
	TI	ST	0.001	0.762
		TO	0.000	0.952
D6-2	ST	TO	−0.002	0.799
		TI	6.320E−005	0.993
	TO	ST	0.002	0.799
		TI	0.002	0.653
	TI	ST	−6.320E−005	0.993
		TO	−0.002	0.653
Postural stability-single stance				
Static	ST	TO	−0.001	0.878
		TI	−0.005	0.718
	TO	ST	0.001	0.878
		TI	−0.004	0.828
	TI	ST	0.005	0.718
		TO	0.004	0.828
D8	ST	TO	−0.006	0.626
		TI	0.000	0.985
	TO	ST	0.006	0.626
		TI	0.006	0.565
	TI	ST	0.000	0.985
		TO	−0.006	0.565
D2	ST	TO	−0.088[a]	0.013
		TI	−0.042[a]	0.002
	TO	ST	0.088[a]	0.013
		TI	0.047	0.129
	TI	ST	0.042[a]	0.002
		TO	−0.047	0.129
TUG test				
	ST	TO	−1.673[a]	< 0.001
		TI	−1.400[a]	< 0.001
	TO	ST	1.673[a]	< 0.001
		TI	0.273	0.272
	TI	ST	1.400[a]	< 0.001
		TO	−0.273	0.272

Where OSI is Overall Stability Index, APSI is Anterior-Posterior Stability Index, MLSI is Medial-Lateral Stability Index, D8 is dynamic setting 8, D2 is dynamic setting 2, D6-2 is dynamic setting 6–2 and TUG is timed-up and go.
[a] Represents that the mean difference is significant at $\alpha = 0.05$.

the same path to the chair and sit down on it. This activity was performed for the three test conditions (**ST**, **TO** and **TI**) in random order with three trials for each condition. The investigators recorded the total time in seconds to perform this activity, with the following time score (t) interpretations: (1) $t < 10$ s: normal; (2) $10 \le t \le 14$: at risk of fall (3) $15 \le t \le 19$: can ambulate independently and can ascend stairs (4) $t > 30$: needs help with seating (including toilet seat) and unable to ascend stairs.

Table 4
ANOVA results of APSI for postural stability.

Test type	Toe-position A	Toe-position B	Mean difference (A–B)	Sig
Postural stability-double stance				
Static	ST	TO	0.000	0.824
		TI	0.000	0.968
	TO	ST	0.000	0.824
		TI	0.000	0.976
	TI	ST	0.000	0.968
		TO	0.000	0.976
D8	ST	TO	−0.003	0.277
		TI	0.003	0.328
	TO	ST	0.003	0.277
		TI	0.006	0.144
	TI	ST	−0.003	0.328
		TO	−0.006	0.144
D2	ST	TO	−0.025[a]	0.005
		TI	−0.029[a]	0.023
	TO	ST	0.025[a]	0.005
		TI	−0.004	0.445
	TI	ST	0.029[a]	0.023
		TO	0.004	0.445
Postural stability-single stance				
Static	ST	TO	0.001	0.829
		TI	0.000	0.969
	TO	ST	−0.001	0.829
		TI	0.000	0.976
	TI	ST	0.000	0.969
		TO	0.000	0.976
D8	ST	TO	−0.004	0.285
		TI	0.003	0.338
	TO	ST	0.004	0.285
		TI	0.007	0.145
	TI	ST	−0.003	0.338
		TO	−0.007	0.14
D2	ST	TO	−0.057[a]	0.002
		TI	−0.027[a]	0.036
	TO	ST	0.057[a]	0.002
		TI	0.031[a]	0.012
	TI	ST	0.027[a]	0.036
		TO	−0.031[a]	0.012

Where APSI is Anterior-Posterior Stability Index, D8 is dynamic setting 8 and D2 is dynamic setting 2.
[a] Represents that the mean difference is significant at $\alpha = 0.05$.

2.8. Statistical analysis

Shapiro–Wilk test was applied to the stability index data to assess normality. The data was found to be normally distributed ($p = 0.25$). To avoid inconsistencies in interpretation, the data was normalized to body mass (taking the ratio of stability index with body mass). A repeated measure ANOVA was performed ($\alpha = 0.05$) to find differences between test conditions. All statistics was done using IBM SPSS (SPSS Inc., USA).

3. Results

Table 2 represents mean and standard deviation values of postural stability, risk of fall, TUG scores and foot progression angles. Tables 3–5 represent pairwise comparison results of repeated measures ANOVA for OSI, APSI and MLSI scores respectively.

3.1. Postural stability-double stance

No significant differences were found among **ST**, **TO** and **TI** for static and D8 tests in OSI, APSI and MLSI. However, significant differences were found for D2 in OSI, APSI and MLSI between **ST** and **TO**, and **ST** and **TI** conditions. The results of repeated ANOVA are: for D2-OSI [*F*

Table 5
ANOVA results of MLSI for postural stability. The abbreviations are given in the footnote.

Test type	Toe-position A	Toe-position B	Mean difference (A–B)	Sig
Postural stability-double stance				
Static	ST	TO	−0.005	0.435
		TI	−0.002	0.571
	TO	ST	0.005	0.435
		TI	0.003	0.652
	TI	ST	0.002	0.571
		TO	−0.003	0.652
D8	ST	TO	−0.004	0.736
		TI	−0.001	0.847
	TO	ST	0.004	0.736
		TI	0.002	0.791
	TI	ST	0.001	0.847
		TO	−0.002	0.791
D2	ST	TO	−0.036[a]	0.004
		TI	−0.024[a]	0.008
	TO	ST	0.036[a]	0.004
		TI	0.012	0.064
	TI	ST	0.024[a]	0.008
		TO	−0.012	0.064
Postural stability-single stance				
Static	ST	TO	−0.006	0.446
		TI	−0.003	0.582
	TO	ST	0.006	0.446
		TI	0.003	0.662
	TI	ST	0.003	0.582
		TO	−0.003	0.662
D8	ST	TO	−0.004	0.744
		TI	−0.001	0.852
	TO	ST	0.004	0.744
		TI	0.003	0.797
	TI	ST	0.001	0.852
		TO	−0.003	0.797
D2	ST	TO	−0.056	0.337
		TI	−0.039[a]	0.034
	TO	ST	0.056	0.337
		TI	0.017	0.760
	TI	ST	0.039[a]	0.034
		TO	−0.017	0.760

Where MLSI is Medial-Lateral Stability Index, D8 is dynamic setting 8 and D2 is dynamic setting 2.

(1.733, 10.397) = 6.419, $p = 0.018$], D2-APSI [F(1.114, 6.682) = 10.287, $p = 0.015$], D2-MLSI [F(1.568, 9.413) = 15.366, $p = 0.002$].

3.2. Postural stability-single stance

No significant differences were found among **ST**, **TO,** and **TI** for static and D8 tests in OSI, APSI and MLSI. However, significant differences were found for D2 in OSI, APSI, and MLSI among **ST**, **TO** and **TI** conditions. The results of repeated ANOVA are: for D2-OSI [F(1.538, 6.151) = 15.167, $p = 0.005$], D2-APSI [F(1.904, 7.618) = 27.145, $p < 0.001$], D2-MLSI [F(1.088, 4.352) = 9.06, $p = 0.040$].

3.3. Risk of fall

Repeated measure ANOVA results did not show any significant difference among all conditions.

3.4. TUG test

Repeated measure ANOVA showed significant differences between **ST** and **TO** & **ST** and **TI**. However, no difference was found between **TO** and **TI.** The ANOVA result is: [F(1.405, 19.669) = 22.694, $p < 0.001$]. Fig. 2 represents means and standard deviations of TUG scores. All time values fell under the 'normal' category (< 10 s).

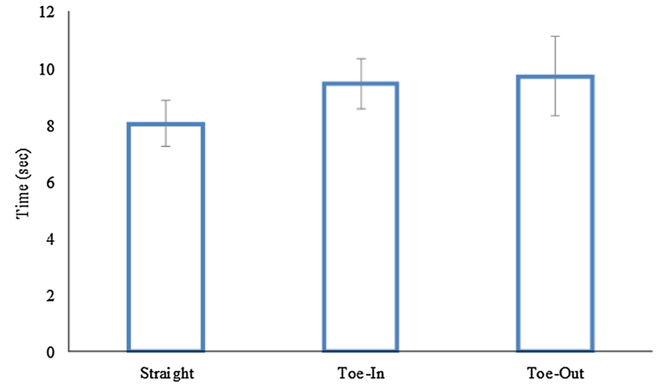

Fig. 2. Mean and standard deviation values for TUG test for the three foot positions.

4. Discussion

A human body's balance can be lost due to prolonged dizziness, impaired vestibular apparatus, physical injury to the head or limbs, visual impairment or postural changes. Therefore, any postural modification aimed at treating a disorder should be designed as such that it does not compromise balance of the person. The purpose of this study was to utilize functional and instrumental tools for assessing postural stability and risk of fall by toe-in and toe-out foot positions under static and varying dynamic conditions.

Under static conditions, the double stance postural stability OSI was not found to be affected significantly by changing the foot progression angle. Insignificant differences were observed, however, which may be indicative of the body's natural tendency to lose balance under postures other than natural. Our participants self-selected the mean toe angle to be 13.8° which is close to the preferred foot angle of 14° during quiet standing reported by McIlroy and Maki [18]. It is expected therefore that any deviations from this naturally preferred angle may cause some difficulty in balancing the body. Similarly, the single stance OSI was not significantly affected by either toe-in posture or toe-out posture. These findings are in-line with those of Schneiders et al., working with the single stance eyes-open condition under static platform [20]. There might be further improvement in this if we allow the participants to train for a certain period with toe-in or toe-out gait to adapt for these modifications. Also, further increasing toe-out and toe-in angles may produce significant differences in postural sway, as reported by Kirby et al., investigating foot progression angle differences as large as 45° using a force platform [17].

A noticeable albeit statistically insignificant finding in toe-out position is that there was an increased variation in MLSI as compared to APSI. This may indicate that the body prefers medio-lateral displacement to regain balance in toe-out position. These results are supported by the conclusions drawn by Mouzat et al. on female subjects with different toe-out angles [19]. No definite conclusions can be drawn as to what balancing strategy was used in toe-in position. This may be further investigated through electromyography as to which muscle or muscle group is activated in this postural modification.

Significant differences were observed when foot rotated externally or internally as compared to normal position with the second-most unstable platform setting (dynamic level 2). The platform with this setting nearly tilts 20° in any direction, thus mimics an extremely unstable terrain. 73.6% and 50% reduction in overall stability was observed during double stance while toeing-out and -in respectively as compared to natural, with no significant difference between them. Although, CoP excursion can be observed in ML and AP directions excessively, but with toe-out posture, excursion in ML was greater while with toe-in, excursion in AP was greater. This difference may be due to the higher mass moment of inertia in ML and AP directions respectively in toe-out and toe-in positions. More pronounced reductions in stability were observed with single stance at this platform setting. 492.8% and 52.2% increase in OSI was obtained with toe-out and toe-in positions respectively. While the difference between toe-out and toe-in was insignificant in OSI, but significant while comparing MLSI and APSI. On an observational note, it was extremely difficult to stand on such platform for the participants and a lot of trials had to be discarded due to tipping over or taking the support of handlebars while toeing-out.

During the TUG test, it was observed that the participants took 20.8% more time while toeing-out and 17.4% more while toeing-in. These significant changes may be due to the lack of practice and may be overcome by adapting to the modified gait because the BBS showed no significant effects in static, dynamic level 8 of postural stability and all settings of the risk of fall. Secondly, this difference in functional and instrumental observation of balance may be since the BBS measures standing balance while TUG is a tool to measure balance during gait.

For this study the sample in consideration consisted of healthy individuals. There can be a debate of generalizing these results to knee osteoarthritis population. The intention behind using healthy individuals was to avoid any confounding factors present in knee osteoarthritis patients that could have influenced the results. As is done by several other studies investigating toe-out and toe-in gait on healthy individuals and suggesting to generalize their results to knee osteoarthritis patients [16,27–30]. Toe-out gait has been reported to be biomechanically similar in terms of kinematics for healthy and knee osteoarthritic participants [31]. Another reason for using healthy participants was to create a baseline data which can be used by other studies wishing to follow this study protocol not only for knee osteoarthritis but also for other types of osteoarthritis and disorders other than osteoarthritis.

As the adverse effects of these toe-in and toe-out gait modifications were observed only at a highly unstable platform and functional balance test, this may indicate that there are differences only during gait or at extremely challenging terrain condition. These effects should be considered while prescribing toe-in and to-out gait modifications to the knee osteoarthritis patients or normal elderly as they already have a compromised balance. For example, it is recommended to avoid these gait modifications at highly unstable terrains or as a more efficient balancing strategy, one can adjust the posture anterio-posteriorly to gain stability and avoid risk of fall.

5. Conclusion

Toe-in and toe-out gait did not show any significant effects on postural stability and risk of fall. Differences were observed only at a highly unstable platform and functional balance test. This may indicate that there are differences only during gait or at extremely challenging terrain condition.

6. Limitations and future directions

A limitation of this study is its small sample size. Larger sample sizes may yield more reliable results. Furthermore, a sample consisting of knee osteoarthritis patients may provide a better understanding of the balance dynamics of toe-in and toe-out gait modifications. Another limitation of this study is that we did not accurately regulate the toe angles of the participants during TUG test. In addition to eliminating these limitations, future studies can employ electromyography with balance testing to identify the strategy adopted by the body in order to maintain or regain balance in toe-out toe-in foot positions.

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

Conceived and designed the experiments: SJK. Performed the experiments: SSK and SJK. Analysed the data: SSK. Contributed reagents/materials/analysis tools: JU. Wrote the paper: SSK. Revising the manuscript critically: SSK, JU, and SJK.

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