Turk J Phys Med Rehab 2025;71(2):167-173
DOI: 10.5606/tftrd.2024.14876
Available online at www.turkishjournalpmr.com

Original Article

The effects of toe-only rocker sole shoes on static balance and kinematics during walking in the elderly

Fatemeh Hemmati[1], Mohammad Taghi Karimi[1,2], Mohammad Hadadi[1,2]

[1]Orthopedic & Rehabilitation Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, Shiraz, Iran

ABSTRACT

Objectives: The aim of this research was to investigate the effects of toe-only rocker (TOR) sole shoes on standing balance and lower limb kinematics during walking in older adults.

Patients and methods: This quasi-experimental, repeated measure study was conducted between January 2019 and April 2020. Twenty-two elderly participants (14 males, 8 females; mean age: 64.8±0.5 years; range, 60 to 80 years) were tested wearing a normal shoe (NS), four types of TOR sole shoes with different rocker angles (10°, 20°, 30°, and 40°), and barefoot (BF). Static balance and gait kinematics were measured by a force plate and motion capture system, respectively.

Results: No significant difference was found in all static balance parameters between different TOR types. There was no significant difference in hip joint kinematics between different shoe conditions. Significantly lower knee joint range of motion was observed in the BF condition compared to NS, TOR 10°, and TOR 20° ($p<0.05$); in TOR 40° compared to NS, TOR 10°, and TOR 20° ($p<0.05$); and in TOR 30° compared to TOR 20° ($p<0.05$). Greater ankle range of motion was observed with NS compared to TOR 30° and TOR 40° ($p<0.001$); in BF compared to NS and different TOR types ($p<0.05$); and in TOR 10° compared to TOR 30° and TOR 40° ($p<0.001$).

Conclusion: The increasing rocker angle in TOR had no negative effect on static balance in the elderly. Therefore, TOR may be used in healthy elderly to decrease movement in the sagittal plane of the ankle joint without disturbance in static balance.

Keywords: Balance, elderly, gait, kinematics, rocker sole shoes.

Aging is associated with abnormalities in gait pattern.[1] In older adults, gait disorders lead to improper consequences such as immobility, fall, and dementia that can cause functional dependency and death.[2]

Decreased range of motion (ROM) of the ankle and first metatarsophalangeal joints was observed in the elderly.[3] Moreover, a reduction in knee and hip joint extension, as well as in ankle dorsiflexion angles during heel contact, was reported in older subjects.[4] DeVita and Hortobagyiet al.[5] reported decreased ankle movements, particularly plantar flexion, at terminal stance and that a delay in dorsiflexion movement during swing phase could lead to falls in the elderly.

Older individuals commonly walk with shorter step length, decreased gait speed,[6,7] increased step width, and double limb support time, which are compensation strategies to increase stability, prevent falls, or decrease the required metabolic energy for movement.[8] However, these alterations may also present as risk factors for falls in the elderly.[9,10]

Footwear is an intermediate segment between the body and support surface, which could potentially affect sensory systems and, consequently, movement. Rocker sole is a commonly prescribed shoe modification that has effects on gait and balance. Some studies have investigated the kinematics of gait with different rocker sole shoes. Long et al.[11] found that walking speed remained unchanged with the

Corresponding author: Mohammad Hadadi, MD. Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Shiraz University of Medical Sciences, 71345-1733 Shiraz, Iran.
E-mail: mhadadito@yahoo.com

Received: February 24, 2024 **Accepted:** July 23, 2024 **Published online:** December 06 2024

Cite this article as: Hemmati F, Karimi MT, Hadadi M. The effects of toe-only rocker sole shoes on static balance and kinematics during walking in the elderly. Turk J Phys Med Rehab 2025;71(2):167-173. doi: 10.5606/tftrd.2024.14876.

use of double rocker sole shoes. Furthermore, small increased flexion was observed at the hip, knee, and ankle during early and mid-stance. Myers et al.[12] measured biomechanical implications of the negative heel rocker shoes in healthy adults. They reported that the most significant kinematic changes occurred at the ankle joint with increased plantarflexion at end stance with the negative heel rocker shoe. Furthermore, significantly increased hip extension and knee flexion were noted. Moreover, increased cadence with no significant change in walking speed or stride length was observed with the negative heel rocker shoe.[12] Van Bogart et al.[13] investigated the kinematics of lower limb joints using toe-only rocker (TOR) sole shoes in normal adults. A significant increase in hip extension during mid-stance and terminal stance was observed with TOR compared to the baseline shoe. In the knee joint, increased flexion during initial contact and loading response and decreased peak knee flexion were observed when using the TOR compared to the baseline shoe. Furthermore, a significant increase in dorsiflexion at initial contact and during loading response, along with increased plantarflexion during terminal stance, was noted with TOR.[13] Thus, the TOR may facilitate forward movement at terminal stance due to the sole geometry of the rocker shoe.

Several studies have reported that maximum plantar flexion strength of the ankle joint decreases at the end stance in the elderly.[14-16] Furthermore, aging was associated with a decrease in walking speed.[7] This can lead to difficulty in forward movement. The TOR is a type of rocker sole shoe characterized by a flat sole in the heel and midfoot and tapered rocker in the forefoot region. The TOR is used to decrease plantar pressure on the toes and forefoot in conditions such as diabetes, decreased mobility, and joint stiffness. Toe-only rocker facilitates push-off, altering movement and load distribution patterns, and has a protective effect on stiffed or immobilized joints due to disease or surgery.[17] Due to the function of TOR to decrease ankle plantar flexion moment, facilitation of movement may occur with this simple shoe modification during the end stance.

To our knowledge, the influence of this simple therapeutic intervention on lower extremity ROM and standing balance has not been explored in elderly subjects. Therefore, the objective of this study was to determine the effects of TOR on standing balance and lower extremities kinematics during walking in the elderly. We hypothesized that the TOR would alter joint kinematics in the lower extremities without a negative effect on static balance in older individuals.

PATIENTS AND METHODS

A convenience sample of 22 older adults (14 males, 8 females; mean age: 64.8±0.5 years; range, 60 to 80 years) participated in this quasi-experimental, repeated measure study conducted at the Orthopedic & Rehabilitation Research Center of Shiraz University of Medical Sciences between January 2019 and April 2020. Inclusion criteria were home residents aged 60 years or older who were able to walk independently, particularly outside their home. Participants were excluded from the study if they had neurological or musculoskeletal disorders, sensory impairment, vestibular or uncorrected visual impairment, a history of falls in the previous six months, or a tumor in the lower limbs. Written informed consent was obtained from each patient.The study protocol was approved by the Shiraz University of Medical Sciences Ethics Committee (date: 26.11.2019, no: IR.SUMS.REHAB.REC.1398.037). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The participants were evaluated in six different conditions. The experimental conditions included four types of TOR shoes with variety of rocker angles (10°, 20°, 30°, and 40°), a normal shoe (NS), and barefoot (BF). All rocker shoes had the same hardness as the NS. All types of lace-up shoes, with an upper made from pseudo leather, had a sole from ethyl vinyl acetate with a hardness of Shore A-85. All shoes had a roomy toe box, a firm heel collar, a flared and board midsole, and a textured sole. In the NS, the heel lift was 1.5 cm, and in the TOR sole shoes, it was 3, 4, 5, and 6 cm for rocker angles of 10°, 20°, 30°, and 40°, respectively. The apex of the rocker was positioned at 60% of the shoe length.[18] All TOR sole shoes were made by an experienced orthotist and individually fitted to each participant.

Static balance was measured by one force platform (Kistler Instrument, Winternthur, Switzerland). Each participant was placed on a force platform in a bipedal standing position, with arms at the sides. The participant was asked to focus on the sign, which was placed 2 m from the wall. Force platform measurements were sampled at rate of 100 Hz, and the data were filtered using a fourth order Butterworth low-pass filter at 10 Hz. Three successful 1-min open-eye trials were collected. A rest period of 1 min was allowed between trials. The average of three successful repetitions for each condition was used. All trials of the six conditions were performed in a randomized order. Center of pressure (COP) parameters were obtained using the following formulas.

Path length$_{AP}$ (m) was calculated using the formula: $\sum_{i=1}^{n-1}\sqrt{(xi+1-xi)2}$.

Path length$_{ML}$ (m) was calculated using the formula: $\sum_{i=1}^{n-1}\sqrt{(yi+1-yi)2}$.

Total path length (m) was calculated using the formula: $\sqrt{\text{path lenght 2 AP+path length 2 ML}}$).

Velocity$_{AP}$ (m/sec) was calculated using the formula: $^{\text{path lenght AP}}/_{t}$.

Velocity$_{ML}$ (m/sec) was calculated using the formula: $^{\text{path lenght ML}}/_{t}$.

Finally, total velocity (m/sec) was calculated using the formula: $\sqrt{V2\ AP+V2\ ML}$.

Twenty-three reflective markers (14 diameters) were mounted to the left and right bony landmarks: anterior/posterior superior iliac spine, medial malleolus, lateral malleolus, iliac crest, acromioclavicular joints, greater trochanters, femoral condyles in medial and lateral, first metatarsal head, fifth metatarsal head, and C7 vertebra. In addition, four cluster markers were located to anterior lateral areas of the thigh and shank bilaterally. Kinematic variables were measured using eight high-speed cameras (Proreflex, Qualysis Track Manager® Ltd., Gothenburg, Sweden) at a frequency of 120 Hz. Data were collected during six conditions and were analyzed from one heel contact to the same heel contact. The participants were asked to walk at a self-selected speed on an 8-m walkway. Five successful walking trials (foot fully on the force plate) were collected per randomized condition.

OpenSim version 3.3 (SimTK, from the National Institutes of Health) was used for the kinematics analysis. The Gait2392 model developed by Delp et al.[19] was used as the biomechanical model. However, the model scaling was performed based on standing trials of the subjects. Markers were labeled in Qualysis and exported as 3CD files. These files were converted to TRC format using Mokka software. A generic model (Gait2392) was then used to calculate the kinematics. The model included 23 degrees of freedom with 12 segments and 92 actuators representing 76 muscles. After scaling based on the anthropometric characteristics of the participant, inverse kinematics was performed to calculate joint angles. Maximum marker error and root mean square (RMS) were less than 2 to 4 cm and less than 2 cm, respectively, during inverse kinematics. Data were normalized to 100% of the gait cycle. The average of joint angles in five successful walking trials was calculated for analysis.

Statistical analysis

Based on the data from a study by Thies et al.,[20] assuming a power of 85% and an alpha of 0.05, we estimated the sample size to be 22 using the G*Power version 3.1.7 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany).

Data were analyzed using SPSS version 16.0 software (SPSS Inc., Chicago, IL, USA). The normality of the data was determined by the Shapiro-Wilk test.

TABLE 1
The results of repeated measures ANOVA on static balance for six different footwear types in older adults

	Shoe conditions						
	BF	NS	TOR10	TOR20	TOR30	TOR40	
Balance parameters	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	*p*
COP path length-AP (m)	0.22±0.10	0.27±0.11	0.27±0.16	0.34±0.26	0.31±0.21	0.32±0.21	0.16
COP path length-ML (m)	0.33±.11	0.35±.14	0.33±.11	0.36±0.18	0.37±0.15	0.37±0.16	0.26
COP total path length (m)	0.40±.14	0.45±.16	0.44±.18	0.52±.29	0.50±.24	0.50±.25	0.09
COP velocity-AP (m/s)	0.02±.01	0.02±.01	0.02±.01	0.03±.02	0.03±.02	0.03±.02	0.19
COP velocity-ML (m/s)	0.03±.01	0.03±.01	0.03±.01	0.03±.01	0.03±.01	0.03±.01	0.26
COP total velocity (m/s)	0.04±.01	0.04±.01	0.04±.01	0.05±.02	0.05±.02	0.05±.02	0.09

BF: Barefoot; NS: Normal shoe; TOR10: Rocker sole shoe with 10° rocker angle; TOR20: Rocker sole shoe with 20° rocker angle; TOR30: Rocker sole shoe with 30° rocker angle; SD: Standard deviation; m: Meter; m/s: Meter per second; Significant difference (p<0.05).

Three repeated measures analysis of variance (ANOVA) was used to determine the effect of six different footwear (independent variable) on static balance parameters (total path length and total velocity of COP in both anterior-posterior and medial-lateral directions), temporospatial parameters (velocity, cadence, stride length, and cycle duration), and kinematics variables during walking (ROM of the hip, knee, and ankle joints). The level of statistical significance was set at $p<0.05$.

RESULTS

The mean height and weight of the participants were 1.61±0.08 m and 72.37±1.18 kg, respectively. Repeated measures ANOVA showed no significant difference in static balance when using rocker shoes with different rocker angles (Table 1).

Temporospatial parameters

The results of ANOVA showed that the main effect of the shoe was significant for walking speed and cadence ($p<0.05$). However, there were no significant differences between footwear conditions for the stride length and cycle duration ($p>0.05$; Table 2).

Pairwise comparisons using the Bonferroni test demonstrated a significant difference in walking velocity between the NS and TOR 40° ($p<0.05$). Walking with the TOR 40° reduced walking velocity compared to the NS ($p=0.029$). There was no significant difference in walking velocity between the other shoe conditions in the elderly ($p>0.05$; Table 2).

Post hoc analysis revealed that the cadence parameter was significantly different between BF and TOR 40° ($p<0.05$). The TOR 40° decreased cadence compared to BF ($p=0.025$). No significant difference was observed between the other shoe conditions ($p>0.05$; Table 2). Increasing the rocker angle from 10° to 30° resulted in an increase in stride length compared to NS, but it was not statistically significant ($p>0.05$).

Kinematics

The findings of ANOVA showed no significant main effect of the shoe in the hip joint in three planes. Consequently, there was no significant difference in hip joint ROM in the three planes with different shoe conditions during walking ($p>0.05$; Table 3).

TABLE 2
Means of temporospatial parameters for different shoe conditions

	Shoe conditions						
	BF	NS	TOR10	TOR20	TOR30	TOR40	
Temporal spatial parameters	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	*p*
Velocity (m/s)	1.06±0.15	1.08±0.14a	1.057±0.14	1.053±0.12	1.03±0.14	0.98±0.16b	0.002[a]
Cadence (step/m)	91.20±10.61a	90.16±10.39	88.65±10.22	88.74±0.85	87.40±9.83	85.40±9.91b	0.005[a]
Stride length (m)	1.38±0.10	1.40±0.14	1.42±0.09	1.42±0.08	1.41±0.09	1.37±0.12	0.129
Cycle duration (s)	1.32±0.18	1.33±0.17	1.36±0.18	1.36±0.13	1.39±0.16	1.39±0.18	0.05

BF: Barefoot; NS: Normal shoe; TOR10: Rocker sole shoe with 10° rocker angle; TOR20: Rocker sole shoe with 20° rocker angle; TOR30: Rocker sole shoe with 30° rocker angle; SD: Standard deviation; m/s: Meter per second; st/m: Number of steps per min; m: Meter; s: Second; a: Significant difference ($p<0.05$).

TABLE 3
The means of the lower extremity joint ROMs in different TOR sole shoes during walking

	Shoe conditions						
	BF	NS	TOR10	TOR20	TOR30	TOR40	
Variables	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	*p*
Hip sagittal	44.41±5.97	45.14±6.10	43.55±4.86	43.78±5.40	45.65±5.51	44.57±5.48	0.18
Hip frontal	14.36±5.39	14.21±4.51	13.60±3.81	13.49±3.67	14.14±3.67	13.96±4.13	0.61
Hip transverse	18.66±4.96	19.30±5.66	20.79±5.31	18.21±4.65	18.93±4.11	20.33±5.41	0.08
Knee sagittal	49.13±4.97	53.16±7.48	52.38±6.21	52.73±5.26	50.92±4.89	49.15±7.04	<0.001
Ankle sagittal	29.54±5.31	26.51±4.96	26.46±5.48	25.35±4.59	22.37±4.03	20.61±4.98	<0.001

BF: Barefoot; NS: Normal shoe; TOR10: Rocker sole shoe with 10° rocker angle; TOR20: Rocker sole shoe with 20° rocker angle; TOR30: Rocker sole shoe with 30° rocker angle; SD: Standard deviation; Significant difference ($p<0.05$).

TABLE 4
Significant pairwise comparisons at the ankle and knee joints

Joint	Conditions	Mean difference	SDE	*p*
Ankle joint				
BF	NS	3.02	0.85	0.002
	TOR10	3.07	1.00	0.006
	TOR20	4.18	0.89	<0.001
	TOR30	7.17	1.07	<0.001
	TOR40	8.92	1.21	<0.001
NS	TOR30	4.14	0.65	<0.001
	TOR40	5.89	0.91	<0.001
R10	TOR30	4.09	0.78	<0.001
	TOR40	5.85	0.86	<0.001
R20	TOR30	2.98	0.59	<0.001
	TOR40	4.74	0.80	<0.001
R30	TOR40	1.75	0.68	0.018
Knee joint				
BF	NS	-4.02	0.98	0.001
	TOR10	-3.25	1.14	0.010
	TOR20	-3.59	0.93	0.001
R20	TOR30	1.80	0.70	0.018
TOR40	NS	-4.00	1.26	0.005
	TOR10	-3.23	1.04	0.006
	TOR20	-3.57	1.00	0.002

SDE: Standard deviation of error; BF: Barefoot; NS: Normal shoe; TOR10: Toe-only rocker sole shoe with 10° rocker angle; TOR20: Toe-only rocker sole shoe with 20° rocker angle; TOR30: Toe-only rocker sole shoe with 30° rocker angle; TOR40: Toe-only rocker sole shoe with 40° rocker angle.

Repeated measure ANOVA revealed a significant main effect of the shoe at the knee and ankle joints in the sagittal plane. Pairwise comparisons using the Bonferroni showed a significant difference in knee joint ROM between BF and NS (p=0.001), TOR 10° (p=0.010), and TOR 20° (p=0.001), with BF maintaining less knee joint ROM compared to the other shoe conditions (Table 3). Furthermore, a significantly lower knee joint ROM was observed in TOR 40° compared to NS (p=0.005), TOR 10° (p=0.006), and TOR 20° (p=0.002). In addition, a significantly lower knee joint ROM was observed in TOR 30° compared to TOR 20° (p=0.018; Table 4).

At the ankle joint, pairwise comparisons showed that wearing an NS (p=0.002), TOR 10° (p=0.006), TOR 20° (p<0.001), TOR 30° (p<0.001), and TOR 40° (p<0.001) resulted in a decrease in ankle joint ROM compared to BF. Furthermore, a higher ankle joint ROM was found with NS compared to TOR 30° and TOR 40° (p<0.001), and a higher ankle ROM was observed with TOR 10° compared to TOR 30° and TOR 40° (p<0.001). A TOR 20° produced more ankle ROM than TOR 30° and TOR 40° (p<0.001). Finally, TOR 30° resulted in a higher ankle ROM compared to TOR 40° (p=0.018; Table 3).

DISCUSSION

Older individuals have reduced ROM and strength of the ankle joint. Toe-only rocker sole shoes decrease loads applied to the forefoot and toe regions and may facilitate forward movement at the end stance.

This study investigated the influence of TOR on static balance and kinematics measurements during walking in the elderly. It was hypothesized that the alteration of rocker angles in TOR sole shoes would change joint kinematics in the lower extremities without a negative effect on static balance in the elderly.

Substantial increase of toe clearance due to increase of the rocker angle (from 10° to 15°) without any disturbance in walking stability was demonstrated in a previous study.[20] Aksenov[17] reported that TOR sole shoes with a heel height of 4.5 cm, rocker position at 55% of shoe length, and 20° rocker angle had no effect on kinematics of hip and knee joints but led to a significant decrease of loading on the calf muscle.

Greater COP speed[21] and greater COP sway in the upright posture were reported in an elderly group with previous falls compared to no falls.[22] Therefore, maintenance of the static balance is important in the elderly. Our study demonstrated that increasing rocker angles has no negative effect on standing balance in the elderly.

The TOR 40° caused a significant decrease in walking velocity compared to the NS. This may be due to the 6-cm heel of the TOR 40°. Given that the high heel height of the shoe is a known risk factor of falling in the elderly, the decrease in walking velocity may be attributed to feeling instability with this type of shoe to maintain balance. In Thies et al.'s[20] study, the speed of walking significantly decreased with 20° rocker shoes. With TOR 10° and TOR 15°, the walking speed was unchanged.[20] In our study, a significant decrease in cadence with TOR 40° was detected, which may attributed to the decrease in velocity when walking. Stride length and cycle duration measurements showed relatively similar results with rocker shoes with different rocker angles. Conversely, Van Bogart et al.[13] demonstrated a significant increase in cadence and a decrease in stride length with TOR sole shoes. However, their study was performed on able-bodied adults.

In other studies on rocker sole shoes, it has been found that these shoes increase cadence.[12,13] In our study, TOR sole shoes had no effect on temporospatial parameters. Only the TOR 40° resulted in a significant decrease in cadence compared to the BF condition. However, this reduction in cadence appears to be exclusively related to the structure of the TOR 40°, specifically its greater weight compared to the other shoes and its heel lift of 6 cm, rather than the presence of the rocker sole in this shoe.

No kinematic changes were observed at the most proximal joint, the hip, in three movement planes. The predominant kinematic changes were at the ankle and knee joints. Comparison of ankle and knee joints kinematics between all rocker sole shoes generally found that as the rocker angles increased, ROM of the ankle and knee joints decreased in the sagittal plane. Rocker sole is a shoe modification in the AP direction. This sole geometry in TOR sole shoes may facilitate ankle joint movement, reduce the required ankle motion at the end stance in sagittal plane, and may decrease loading of the ankle joint. Van Bogart et al.[13] found a significant increase in knee flexion at initial contact and during loading response with TOR sole shoes compared to the baseline shoe. In contrast, our findings demonstrated a decrease in knee ROM with all TOR sole shoes compared to the NS. This may be due to the differing ages of the participants in the two studies and the different types of TOR sole shoes used in the two studies.

Toe-only rocker sole shoes mimic the action of the ankle joint, assist roll-off, improve toe clearance, and simulate forefoot dorsiflexion. As demonstrated in the results, using TOR sole shoes with rocker angles of 10°, 20°, and 30° can facilitate movement in the ankle joint without balance perturbance in a static condition. This becomes more important for elderly individuals with limited ankle ROM, such as those with ankle arthritis, who still have good stability in the proximal joints (knee and hip). In our previous study, TOR sole shoes had no adverse effect on local dynamic balance during walking on a treadmill.[23] Therefore, TOR sole shoes can be used in clinical prescriptions without a threat to postural balance in elderly people.

This study had some limitations. The participants in this study were healthy elderly individuals. As rocker soles can alter kinematics and plantar pressure, we suggest evaluating the effects of rocker sole shoes in the elderly with frequent degenerative disorders in the lower extremity joints, such as osteoarthritis. Additionally, the long-term evaluation of TOR sole shoes on gait alterations in the elderly is recommended.

In conclusion, the findings demonstrated that a higher rocker angle in TOR sole shoes had no negative effect on static balance in the elderly. Increasing rocker angles had no significant effect on hip joint motion compared to the NS. Furthermore, with increasing rocker angles, knee joint ROM decreased, particularly in TOR 30° and TOR 40° compared to the NS. In the ankle joint, greater rocker angles caused a decrease in ankle joint movement in the sagittal plane. Therefore, shoes with TOR soles may be used to decrease movement in the sagittal plane of the ankle joint for healthy elderly without disturbance in static balance.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed equally to this article.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: This work was supported by a grant from the Shiraz University of Medical Sciences (Grant Number: 18292).

REFERENCES

1. Bloem BR, Haan J, Lagaay AM, van Beek W, Wintzen AR, Roos RA. Investigation of gait in elderly subjects over 88 years of age. J Geriatr Psychiatry Neurol 1992;5:78-84. doi: 10.1177/002383099200500204.
2. Guralnik JM, Ferrucci L, Pieper CF, Leveille SG, Markides KS, Ostir GV, et al. Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. J Gerontol A Biol Sci Med Sci 2000;55:M221-31. doi: 10.1093/gerona/55.4.m221.
3. Scott G, Menz HB, Newcombe L. Age-related differences in foot structure and function. Gait Posture 2007;26:68-75. doi: 10.1016/j.gaitpost.2006.07.009.
4. Winter DA, Patla AE, Frank JS, Walt SE. Biomechanical walking pattern changes in the fit and healthy elderly. Phys Ther 1990;70:340-7. doi: 10.1093/ptj/70.6.340.
5. DeVita P, Hortobagyi T. Age causes a redistribution of joint torques and powers during gait. J Appl Physiol (1985) 2000;88:1804-11. doi: 10.1152/jappl.2000.88.5.1804.
6. Kirkwood RN, de Souza Moreira B, Vallone ML, Mingoti SA, Dias RC, Sampaio RF. Step length appears to be a strong discriminant gait parameter for elderly females highly concerned about falls: A cross-sectional observational study. Physiotherapy 2011;97:126-31. doi: 10.1016/j.physio.2010.08.007.
7. Prince F, Corriveau H, Hebert R, Winter D. Gait in the elderly. Gait & Posture 1997;5:128-35. doi: 10.1016/S0966-6362(97)01118-1.
8. Pavol MJ, Owings TM, Foley KT, Grabiner MD. Gait characteristics as risk factors for falling from trips induced in older adults. J Gerontol A Biol Sci Med Sci 1999;54:M583-90. doi: 10.1093/gerona/54.11.m583.
9. Imms FJ, Edholm OG. Studies of gait and mobility in the elderly. Age Ageing 1981;10:147-56. doi: 10.1093/ageing/10.3.147.
10. Guimaraes RM, Isaacs B. Characteristics of the gait in old people who fall. Int Rehabil Med 1980;2:177-80. doi: 10.3109/09638288009163984.
11. Long JT, Klein JP, Sirota NM, Wertsch JJ, Janisse D, Harris GF. Biomechanics of the double rocker sole shoe: Gait kinematics and kinetics. J Biomech 2007;40:2882-90. doi: 10.1016/j.jbiomech.2007.03.009.
12. Myers KA, Long JT, Klein JP, Wertsch JJ, Janisse D, Harris GF. Biomechanical implications of the negative heel rocker sole shoe: Gait kinematics and kinetics. Gait Posture 2006;24:323-30. doi: 10.1016/j.gaitpost.2005.10.006.
13. Van Bogart JJ, Long JT, Klein JP, Wertsch JJ, Janisse DJ, Harris GF. Effects of the toe-only rocker on gait kinematics and kinetics in able-bodied persons. IEEE Trans Neural Syst Rehabil Eng 2005;13:542-50. doi: 10.1109/TNSRE.2005.858460.
14. Karamanidis K, Arampatzis A. Evidence of mechanical load redistribution at the knee joint in the elderly when ascending stairs and ramps. Ann Biomed Eng 2009;37:467-76. doi: 10.1007/s10439-008-9624-7.
15. Andriacchi TP, Mündermann A, Smith RL, Alexander EJ, Dyrby CO, Koo S. A framework for the in vivo pathomechanics of osteoarthritis at the knee. Ann Biomed Eng 2004;32:447-57. doi: 10.1023/b:abme.0000017541.82498.37.
16. Baliunas AJ, Hurwitz DE, Ryals AB, Karrar A, Case JP, Block JA, et al. Increased knee joint loads during walking are present in subjects with knee osteoarthritis. Osteoarthritis Cartilage 2002;10:573-9. doi: 10.1053/joca.2002.0797.
17. Aksenov A. An investigation into the relationship between rocker sole designs and alteration to lower limb kinetics, kinematics and muscle function during adult gait. University of Salford (United Kingdom); 2014.
18. van Schie C, Ulbrecht JS, Becker MB, Cavanagh PR. Design criteria for rigid rocker shoes. Foot Ankle Int 2000;21:833-44. doi: 10.1177/107110070002101007.
19. Delp SL, Anderson FC, Arnold AS, Loan P, Habib A, John CT, et al. OpenSim: open-source software to create and analyze dynamic simulations of movement. IEEE Trans Biomed Eng 2007;54:1940-50. doi: 10.1109/TBME.2007.901024.
20. Thies SB, Price C, Kenney LP, Baker R. Effects of shoe sole geometry on toe clearance and walking stability in older adults. Gait Posture 2015;42:105-9. doi: 10.1016/j.gaitpost.2015.04.011.
21. Maeda Y, Tanaka T, Miyasaka T, Shimizu K. A preliminary study of static and dynamic standing balance and risk of falling in an independent elderly population with a particular focus on the limit of stability test. J Phys Ther Sci 2011;23:803-6. doi: 10.1589/jpts.23.803.
22. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. Neurobiol Aging 1989;10:727-38. doi: 10.1016/0197-4580(89)90010-9.
23. Hemmati F, Haghpanah SA, Karimi MT, Mardani MA, Fadayevatan R. Nonlinear analysis of dynamic stability in walking with toe-only rocker sole shoes in elderly. Med Eng Phys 2022;99:103738. doi: 10.1016/j.medengphy.2021.103738.