ORIGINAL PAPER

Physiotherapy Quarterly (ISSN 2544-4395)
2022, 30(2), 24–29

Effect of backward walking training on foot posture and balance in flat foot adults

DOI: https://doi.org/10.5114/pq.2021.108668

Marwa S. Saleh[1], Doaa A. Elimy[1], Amal H. Ibrahim[1], Ashraf N. Moharam[2]

[1] Department of Basic Science, Faculty of Physical Therapy, Cairo University, Giza, Egypt
[2] Faculty of Medicine, Cairo University, Giza, Egypt

Abstract

Introduction. Flat foot changes the posture of the foot and affects dynamic balance. Backward walking is a novelty in rehabilitative clinic; it improves strength and balance. The aim of this study was to investigate the effect of backward walking training on foot posture and dynamic balance in flat foot subjects.

Methods. Overall, 44 participants with bilateral mobile flat foot, aged 19–35 years, were randomly assigned to 2 equal groups. Group A received backward walking training 3 times/week for 6 weeks, in addition to traditional physical therapy exercises. Group B received traditional physical therapy exercises only, 3 times/week for 6 weeks. Before and after treatment, foot posture was assessed with the Foot Posture Index and balance was evaluated with the HUMAC Balance System through the Limits of Stability test.

Results. Statistical analysis revealed a significant reduction in the Foot Posture Index and a significant increase of the Limits of Stability in both groups after treatment compared with the pre-treatment status ($p < 0.001$). Comparison between the groups after treatment showed a significant decrease in the Foot Posture Index in group A compared with group B ($p < 0.05$) and a significant increase in the Limits of Stability in group A compared with group B ($p < 0.001$).

Conclusions. Backward walking training as an addition to physical therapy exercises of flat foot can improve foot posture and enhance balance in comparison with physical therapy exercises alone.

Key words: dynamic balance, flat foot, backward walking training, foot posture

Introduction

Flat foot is considered to be a flattening of the medial longitudinal arch [1], which is one of the most frequent musculoskeletal disorders, affecting nearly 20% of the general population [2] and followed by a higher incidence of lower limb injury [3]. Foot dysfunction can cause disorders in the whole body biokinematic chain [4]. Individuals with flat-arched foot have been reported to have substantially higher pronation in stance than those with high arching, and when the plantar intrinsic foot muscles were fatigued, a change in foot posture towards a pronated position occurred [5]. This impedes the foot supportive function and causes overloading of the foot intrinsic muscles to maintain upright posture, increasing the need for further postural control and leading to balance problems [6].

Balance could be defined as being capable of maintaining centre of gravity throughout the base of support [1], which is critical to most functional daily activities. Preserving balance is a major challenge for the human body to prevent falling risks that lead to serious harms and injuries [7].

Among the possible exercise methods to improve flat foot are short foot exercises, which involve sensory-motor training, activate the intrinsic foot muscles, maintain the medial longitudinal arch, and increase the balance of the body [6]. Also, the towel-curl exercise strengthens the extrinsic foot muscles and corrects flat foot. These exercises increase the arch support and improve foot posture [8].

Walking is an easy, popular, and cost-effective form of exercise that works well for health and promotes quality of life [9]. In a reversal of normal walking, referred to as retro-walking or backward walking (BW), the toes first reach the ground and the step finishes with the heel [10]. This mode of exercise training has been applied by numerous scholars in the USA [11], China, Japan, and Europe [12], and recently, researchers and rehabilitation professionals are paying attention to this innovative and effective intervention [10].

From the point of view of rehabilitation, BW is regarded as a successful non-invasive modality for improving muscle action and lower extremity strength [13]. Being a novel and unusual task, it results in more motor units recruitment [14], which in turn strengthens the lower limb muscles [13]. It has been reported that BW (Reverse Tandem Gait) and other exercises of the plantar short foot muscles can improve the foot posture when assessed by the Foot Posture Index in long distance runners; also, the exercises applied could have beneficial effects on foot alignment [5].

Moreover, training in a backward direction has been shown to improve the human body balance [14–16]. Recent evidence has indicated that when BW is combined into a training program, the balance and stability can be improved in children with Down syndrome [17]. Furthermore, El-Basatiny and Abdel-Aziem [14] examined the effect of treadmill BW (25 minutes/day, 3 days/week for 12 weeks) on postural balance in children with hemiparetic cerebral palsy and the results revealed that BW training added to the traditional physical therapy program improved postural stability and balance. Research performed by Hao and Chen [15] to investigate the effect of BW exercise in healthy boys in which BW training was applied in the experimental group but not in the control group demonstrated improvement of balance in the experimental group as compared with the control one;

Correspondence address: Doaa A. Elimy, Department of Basic Science, Faculty of Physical Therapy, Cairo University, 12612, Giza, Egypt, e-mail: do3aayoub25@gmail.com

Received: 05.05.2020
Accepted: 03.08.2020

Citation: Saleh MS, Elimy DA, Ibrahim AH, Moharam AN. Effect of backward walking training on foot posture and balance in flat foot adults. Physiother Quart. 2022;30(2):24–29; doi: https://doi.org/10.5114/pq.2021.108668.

the improvement was maintained 3 months after the BW training.

For this reason, therapists in rehabilitation centres have been using BW on a level ground or a treadmill owing to its respectable effects. Nevertheless, to our knowledge, there is no published literature documenting the impact of BW in flat foot subjects. So, the current study was conducted to explore the effect of BW training on foot posture and dynamic balance in flat foot participants.

Subjects and methods

Study design

This randomized, controlled trial was carried out at the outpatient clinic and the balance laboratory of the Faculty of Physical Therapy, Cairo University, Egypt, during the period of 2018–2019.

Sample size calculation

The G*Power software (version 3.1.6) was used to estimate the required sample size *a priori*. The calculation depended on the *t*-test; the rate of type I error was set at 5% (alpha-level: 0.05), the effect size of the main outcome variable (Limits of Stability) gained from a pilot study of 10 subjects was 1.27, and the rate of type II error was 95%. For this study, the appropriate minimum sample size was 36 subjects.

Subjects

Overall, 44 subjects (37 females and 7 males) with mobile flat foot were recruited from the Faculty of Physical Therapy (undergraduate and postgraduate) college on a voluntary basis. During assessment for eligibility, 16 subjects dropped out during treatment: 12 refused to participate in the study and 4 did not meet the criteria for inclusion. A total of 44 subjects completed the study, as shown in Figure 1. The participants received both verbal and written explanation of the study and if they decided to participate, they signed an informed consent that was approved by the University of Cairo Institutional Review Board. The consenting subjects were randomly assigned to 2 groups of equal numbers. The randomization was performed by a random generator and permuted blocks of same size.

Group A (study group) underwent BW exercise in combination with traditional physical therapy exercises. Group B (control group) received traditional physical therapy exercises alone. The training was applied 3 times/week for 6 weeks.

The subjects were included in the study after satisfying the following criteria:

1. Bilateral mobile flat foot between +6 and +9 as determined by the Foot Posture Index [18].
2. Age of 19–35 years.
3. Body mass index of 18–25 kg/m^2.

Subjects were excluded if they had:

1. History of lower extremity operation or cerebral concussions.
2. Discrepancy of leg length.
3. Visual or vestibular disorders or any neurological issues affecting balance.
4. Other foot deformities (e.g. hallux valgus).

Instruments

Foot Posture Index version 6 (FPI-6) was used to evaluate foot posture. It is a clinical tool to assess the foot from all planes without using special instruments. It has demonstrated validity [19], perfect intra-rater reliability [20], and accurate reliability between raters [21]. Cornwall et al. [20] found excellent intra-rater results (ICC: 0.92–0.93) and moderate inter-rater results (0.52–0.65), while Terada et al. [22] reported intra-rater reliability between 2 sessions as ICC 3.3 = 0.95.

HUMAC Balance System served to evaluate dynamic balance. It is a computerized dynamic posturography device (Stoughton, MA, USA, 2013) in which the force platform sensors measure the forces produced by multi-directional body movement on the basis of the technology of the Wii balance boards. It has been validated versus the classical force

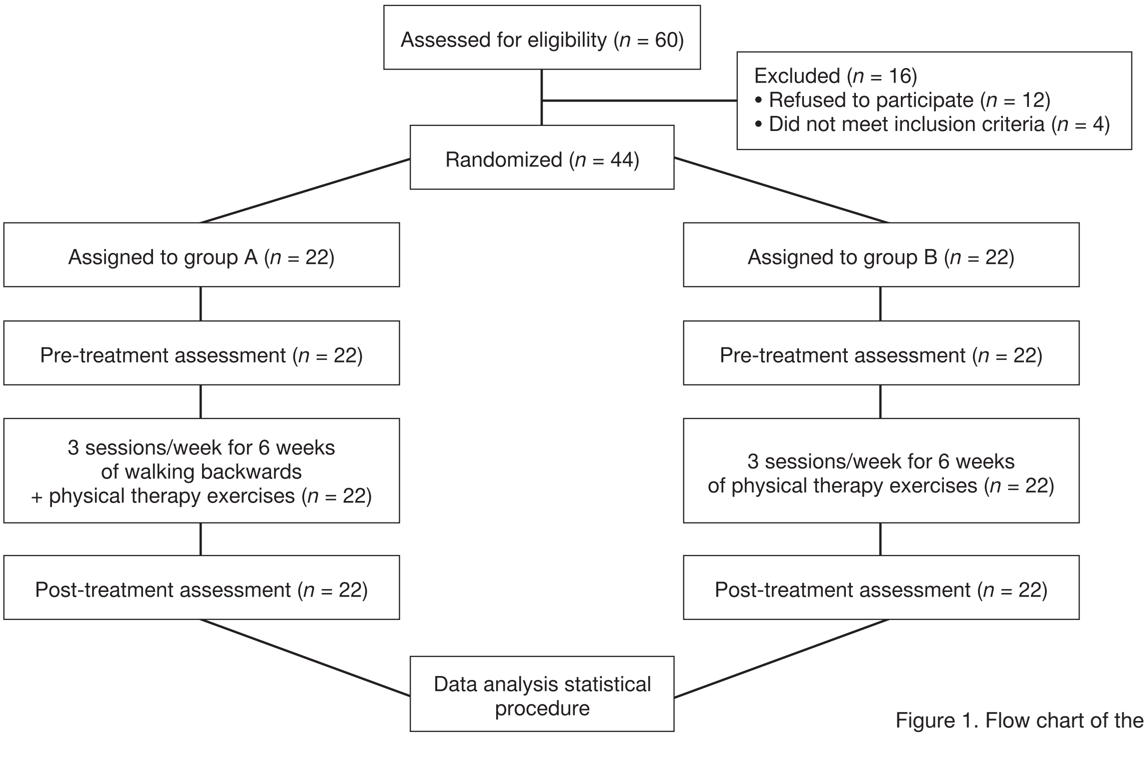

Figure 1. Flow chart of the study

plate [23]. The evaluation was carried out through the Limits of Stability test, which was proven to be accurate in dynamic balance assessment, with a range of reliability from moderate to good (ICC 2,1: 0.73–0.96) [24].

Procedure

To determine flat foot mobile type, the tiptoe test was performed in which the subject was asked to stand on tiptoes of one foot and, after that, repeat the same step for the other foot. The foot is considered mobile when the arch is absent, disappears in standing position, and appears again when standing on tiptoes [25]. Then, flat foot was evaluated with the Foot Posture Index, in which the subject was instructed to stand up, take a few strides, and then stop and look forward with their arms next to them. The 6-item index includes the following components [19]: talar head palpation, curvature at the lateral malleoli, inversion/eversion of the calcaneus, talonavicular bulging, congruence of the medial longitudinal arch, and abduction/adduction of the forefoot on the rearfoot.

Each point of the index is simply graded 0 for neutral, with a minimum score of –2 for clear supination signs and +2 for positive pronation signs. By summation the overall score, the foot is considered normal for a score from 0 to +5, pronated for +6 to +9, highly pronated for +10 to +12, supinated for –1 to –4, and highly supinated for –5 to –12 [18]. All subjects included in the study ranged from +6 to +9.

For dynamic balance assessment, the participant was asked to stand without shoes on the platform with their hands beside. Before commencing the actual measurement, test procedures were explained to the subject and the test was repeated until the individual became acquainted with the apparatus and understood the test. The subject was then asked to move a cursor representing their body, follow the illuminated target with the body, and stay there for a second until another target was lighted; then, they had to move to catch it and stabilize on it until another target was lightened, and so on. The test measures 8 randomly performed directional movements: forward, forward-right, right, back-right, backward, back-left, left, forward-left. The test was repeated 3 times, and the results were calculated as percentage of the overall time on target [23].

Interventions

Group A received BW training in combination with traditional physical therapy exercises for flat foot while group B received only traditional physical therapy exercises for flat foot.

Backward walking training

The subject was asked to walk for 30 minutes on a level treadmill, zero inclination, with a warming up and cooling down period (5 minutes for each period). The individual walked at their comfortable walking speed. During the warm-up and cool-down periods, ankle toe movements, hamstring and calf stretching, and heel raise were performed. The training was conducted 3 times/week during 6 consecutive weeks [26].

Traditional physical therapy exercises

Short foot exercises. The subject sat on an adjustable chair with hip and knee joints flexed to 90° and the foot resting on the floor with a towel underneath. The participant was then asked to supinate the foot and approximate the first metatarsal head towards the heel, raise the medial longitudinal arch without bending the toes to avoid compensation from the extrinsic foot muscle, hold for 10 seconds, then allow the foot to relax for 1–2 seconds, and repeat the exercise 50 times for each foot. The training started from the sitting position and progressed to standing position after 3 weeks, with a total training period of 6 weeks [8].

Towel-curl exercise. Sitting in the previous position, the subject put their toes on the edge of the towel, then pulled the towel by flexing the toes, and maintained a strong grip for 5 seconds. The exercise was performed in 3 sets of 10 repeats [8].

Heel raise exercise. The participant was requested to stand behind a chair for support, put their hands on the back of the chair, and then raise their body for 5 seconds on the toes. Afterwards, they removed their hands from the chair and descended slowly to strengthen the ankle plantar-flexor muscles. The subject carried out 3 sets of 10 repeats [27].

Calf stretch. At the end of the exercise program, the individual was asked to perform self-static stretching for the calf muscle, which consisted of standard gastrocnemius and soleus stretching against a wall, with the knee straight and with the knee bent [28], for 15 seconds with a relaxation period of 3 seconds. The stretching was done in 10 repeats [29].

Statistical analysis

The statistical analysis was performed with the SPSS software version 22 (IBM SPSS, Chicago, IL, USA). Prior to the analysis, the normality of data was checked by using the Shapiro-Wilk test. The data were normally distributed, so they were analysed with parametric testing. MANOVA was conducted to compare the effects on the Foot Posture Index and Limits of Stability within and between groups. The significance level for the statistical testing was assumed at $p < 0.05$.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee of the Faculty of Physical Therapy, Cairo University (approval No.: P.T. REC/012/001725) and registered at the Pan African Clinical Trials Registry (registry No.: PACTR201809729113967).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Demographic data

The unpaired *t*-test revealed no significant difference between the 2 groups in age, weight, height, or body mass index ($p > 0.05$), as shown in Table 1.

Table 1. Demographic data of both groups

Parameters	Group A (mean ± *SD*)	Group B (mean ± *SD*)	*t*	*p*	Sig.
Age (years)	21.09 ± 1.87	21.86 ± 3.8	–0.85	0.39	NS
Weight (kg)	61.04 ± 6.87	62.4 ± 9.88	–0.53	0.59	NS
Height (cm)	164.22 ± 8.08	164.77 ± 9.7	–0.2	0.84	NS
BMI (kg/m^2)	22.58 ± 1.41	22.85 ± 1.73	–0.55	0.58	NS

Sig. – significance, BMI – body mass index, NS – not significant

Table 2. The right and left Foot Posture Index and Limits of Stability for both groups

Parameters	Group A (mean ± *SD*)		Group B (mean ± *SD*)		Within-group comparison (*p*)		Between-group comparison (*p*)	
	Before	After	Before	After	Group A	Group B	Before	After
Right FPI (score)	7.54 ± 0.8	6.45 ± 0.5	7.59 ± 0.79	6.95 ± 0.84	0.001*	0.001*	0.85	0.02*
Left FPI (score)	7.86 ± 0.83	6.5 ± 0.8	8.04 ± 0.65	7.45 ± 0.85	0.001*	0.001*	0.42	0.001*
LOS (%)	33.68 ± 6.23	50.9 ± 4.6	35.31 ± 8.71	43.5 ± 7.43	0.001*	0.001*	0.47	0.001*

FPI – Foot Posture Index, LOS – Limits of Stability; * significant values

Within-group analysis

Within-group comparison between the pre-treatment and post-treatment status revealed a significant decrease in right and left Foot Posture Index in groups A and B ($p < 0.001$). Similarly, both groups showed a significant increase in Limits of Stability after treatment compared with before treatment ($p < 0.001$).

Between-group analysis

Between-group comparison before treatment presented a nonsignificant difference ($p > 0.05$), while the comparison between the groups after treatment revealed a significant decrease in right and left Foot Posture Index in group A compared with group B ($p < 0.05$) and a significant increase in the Limits of Stability in group A compared with group B ($p < 0.001$), as shown in Table 2.

Discussion

The current study aimed at investigating the impact of BW training on foot posture and dynamic balance in flat foot subjects. The results showed improvements for both measured variables in both groups; however, the study group, receiving BW training in addition to traditional physiotherapy exercises, presented better improvement than the control group, receiving only traditional physiotherapy exercises.

With regard to foot posture, the improvement produced by BW training can be attributed to an increase in the muscle strength of the lower limbs as a result of further activation of the motor cortex [30] to perform this unconventional walking form, which puts more stress on the working muscles, recruits more motor units [14], and enhances muscle strength by its role [13].

Another possible mechanism for the improving foot posture may be due to the increased strength of tibialis anterior and calf muscles that had previously been proven to act as medial longitudinal arch dynamic stabilizers [31].

The results of this study are in accordance with those achieved by Sulowska et al. [5], who confirmed that BW (Reverse Tandem Gait) in addition to other plantar short foot muscle exercises modified the foot posture from a pronated to a neutral foot, measured by the Foot Posture Index, and these exercises could improve foot alignment.

The results are consistent with those of a study by Rosenbaum et al. [32], who detected higher electromyography amplitudes in such muscles as gluteus medius, rectus femoris, vastus lateralis, and semitendinosus during the BW stance phase, while there was a higher activation of rectus femoris and soleus muscles during the swing phase. Furthermore, Masumoto et al. [33] found a greater activation of tibialis anterior in 10 healthy males who walked backwards on an underwater treadmill.

Also, Jansen et al. [34] reported that some muscles (i.e., dorsiflexors) showed specific directional contribution with BW. Grasso et al. [35] demonstrated more activation from tibialis anterior and lateral gastrocnemius muscles during BW; the activation of these muscles is essential, as they support the medial longitudinal arch [30].

In addition, Winter et al. [36] found the medial gastrocnemius exhibiting extra burst of increased activity before and after heel-off during BW. Moreover, notable changes in gastrocnemius electromyographic activity were reported by Cipriani et al. [37] at the initial contact at 0–10% inclination grade, as well as increased demands with the inclined BW.

Training a person in BW can provide neural adaptability that improves the efficiency of the neuromuscular system [14]. Schneider and Capaday [38] stated that daily training of BW induced gradual adaptation of the soleus H-reflex.

Finally, flat-arched foot has been declared to cause ground reaction forces to deviate in the medium during the gait stance phase: the foot pressure pattern is changed, leading to higher pressure [39]. With BW, the pattern of foot contact is reversed, the ground reaction forces at contact are reduced, and the plantar pressure is redistributed [10]. These changes may reflect an improvement of foot owing to BW exercise.

Concerning dynamic balance, our results were consistent with those obtained by Weng et al. [40], who showed a significantly greater improvement in balance and sensorimotor function in patients treated on a treadmill with a BW program in combination with conventional rehabilitation training compared with subjects receiving conventional rehabilitation only. Moreover, Takami and Wakayama [41] used BW treadmill partial body weight support in acute stroke patients with unstable gait and found increased mobility during the early acute stroke phase.

The observations of this study come in agreement with the research by Abdou et al. [42], who found that treadmill BW training could be used to enhance the mediolateral stability index of hemiparetic cerebral palsy children. Furthermore, the results of the randomized, controlled trial conducted by Zhang et al. [10] implied that BW had an ameliorating effect on balance ability and muscle strength in patients with diabetic peripheral neuropathy. This was in line with Zhang et al. [13], who measured static balance skills in elderly women undergoing BW training and compared them with those in the control group without BW training. The results favoured the experimental group intervention, with diminished fluctuation of the static gravity centre with eyes closed.

Consequently, the superiority of BW training is justified by a rational fact that in BW, the toes contact first and the step finishes off with the heel; thus, the pattern is unusual and unfamiliar to the subject, so they pay attention and become more cautious because of the feeling of instability. This increases motor cortex activity [30] to maintain postural stability [17].

The mechanism by which BW improves the dynamic balance can be ascribed to increased cortical activation as it has been shown that with BW, the concentration of oxygenated haemoglobin increases in the supplementary motor area, pre-central gyrus, and the superior parietal lobule when measured by functional near-infrared spectroscopy [30]. This level of oxygenated haemoglobin, as noted by Shibuya et al. [43], is directly associated with cortical activation.

Another possible explanation of these results may be the absence of visual information on the direction of walking, calling for additional stabilizing mechanisms that could rely on the other sensor-motor system, such as muscle strength and proprioception, to compensate for the lack of visual feedback and maintain dynamic balance [36]. Yang et al. [16] stated that BW improved perceptual responses and the changes in the environment might help to advance neuromuscular control, proprioception, and protective reflexes owing to lack of visual signals.

Changes in muscle strength in lower limbs induced by BW exercise may be another plausible explanation as the motor system has a significant contribution to preserving balance. It has been declared that the plantar flexors and dorsiflexors play a central role in maintaining balance on support for single and bilateral extremities. Also, gastrocnemius and soleus are instrumental in postural adjustment [44]. Furthermore, Hoogkamer et al. [45] observed pronounced crossed reactions in the anterior tibialis to maintain stability and balance during BW.

Limitations

The main limitation for this study was the lack of blinding on the assessor part. An effort was made to standardize the procedures and minimize any possible bias due to the lack of blindness. There were only 6 weeks of treatment, which is considered to be a relatively short period. In addition, the study did not examine the long-term impacts or follow-up.

Conclusions

According to this study, BW training provides an additional effect for flat foot subjects as it improves foot posture and dynamic balance and can be incorporated into the rehabilitation approach of flat foot. Future research is needed to investigate the immediate and long-term effects, as well as a follow-up of BW training in flat-arched foot; also, replication of this study with diverse treadmill inclinations is advised. Further work is crucial to examine the foot muscle activity and plantar pressure changes as a result of BW training.

Acknowledgements

The authors express their appreciation to the individuals who took part in the study. Great thanks to the colleagues and staff, Al Shaymaa S. Abd El-Azeim in particular, for their enormous help and effort.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

Funding

For this study, no specific grant was received from public, commercial, or non-profit funding agencies.

References

1. Letafatkar A, Zandi S, Khodayi M, Vashmesara JB. Flat foot deformity, Q angle and knee pain are interrelated in wrestlers. J Nov Physiother. 2013;3(2):138; doi: 10.4172/2165-7025.1000138.
2. Bordin D, De Giorgi G, Mazzocco G, Rigon F. Flat and cavus foot, indexes of obesity and overweight in a population of primary-school children. Minerva Pediatr. 2001;53(1):7–13.
3. Williams III DS, McClay IS, Hamill J, Buchanan TS. Lower extremity kinematic and kinetic differences in runners with high and low arches. J Appl Biomech. 2001;17(2):153–163; doi: 10.1123/jab.17.2.153.
4. Szeliga E, Bac A, Kaczor S. The evaluation of foot arch and the distribution of foot-to-ground contact forces in young football players as well as their impact on the occurrence of injuries. Adv Rehab. 2019;33(4):13–18; doi: 10.5114/areh.2019.89822.
5. Sulowska I, Oleksy Ł, Mika A, Bylina D, Sołtan J. The influence of plantar short foot muscle exercises on foot posture and fundamental movement patterns in long-distance runners, a non-randomized, non-blinded clinical trial. PLoS One. 2016;11(6):e0157917; doi: 10.1371/journal.pone.0157917.
6. Moon D-C, Kim K, Lee S-K. Immediate effect of short-foot exercise on dynamic balance of subjects with excessively pronated feet. J Phys Ther Sci. 2014;26(1):117–119; doi: 10.1589/jpts.26.117.
7. Lee K, Lee M, Song C. Balance training improves postural balance, gait, and functional strength in adolescents with intellectual disabilities: single-blinded, randomized clinical trial. Disabil Health J. 2016;9(3):416–422; doi: 10.1016/j.dhjo.2016.01.010.
8. Lynn SK, Padilla RA, Tsang KKW. Difference in static- and dynamic-balance task performance after 4 weeks of intrinsic-foot-muscle training: the short-foot exercise versus the towel-curl exercise. J Sport Rehabil. 2012;21(4):327–333; doi: 10.1123/jsr.21.4.327.
9. Ogilvie D, Foster CE, Rothnie H, Cavill N, Hamilton V, Fitzsimons CF, et al. Interventions to promote walking: systematic review. BMJ. 2007;334(7605):1204; doi: 10.1136/bmj.39198.722720.BE.
10. Zhang X, Zhang Y, Gao X, Wu J, Jiao X, Zhao J, et al. Investigating the role of backward walking therapy in alleviating plantar pressure of patients with diabetic peripheral neuropathy. Arch Phys Med Rehabil. 2014;95(5):832–839; doi: 10.1016/j.apmr.2014.01.003.
11. Yan P, Luo J, Zhang T, Wang X, Zhang X, Zhang L, et al. Physical fitness effect of three backward walking exercises intervention in overweight male college students. Int J Sci. 2015;2(3):1–7.
12. Balraj AM, Kutty RK, Kamraj B, Saji VT. Impact of retro-walking on pain and disability parameters among chronic osteoarthritis knee patients. Physiother Rehabil. 2018;3(2):157; doi: 10.4172/2573-0312.1000157.
13. Zhang S, Lin Z, Yuan Y, Wu X. Effect of backward-walking on the static balance ability and gait of the aged people. Chin J Sports Med. 2008;27:304–307.
14. El-Basatiny HMY, Abdel-Aziem AA. Effect of backward walking training on postural balance in children with hemiparetic cerebral palsy: a randomized controlled study. Clin Rehabil. 2015;29(5):457–467; doi: 10.1177/0269215514547654.
15. Hao W-Y, Chen Y. Backward walking training improves balance in school-aged boys. Sports Med Arthosc Rehabil Ther Technol. 2011;3:24; doi: 10.1186/1758-2555-3-24.

16. Yang Y-R, Yen J-G, Wang R-Y, Yen L-L, Lieu F-K. Gait outcomes after additional backward walking training in patients with stroke: a randomized controlled trial. Clin Rehabil. 2005;19(3):264–273; doi: 10.1191/02692155 05cr860oa.
17. Amini HA, Kalkhoran JF, Salehi M, Jazini F. Effect of backward walking training on improves postural stability in children with Down syndrome. Int J Pediatr. 2016; 4(7):2171–2181; doi: 10.22038/IJP.2016.7103.
18. Redmond AC, Crane YZ, Menz HB. Normative values for the Foot Posture Index. J Foot Ankle Res. 2008;1(1):6; doi: 10.1186/1757-1146-1-6.
19. Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. Clin Biomech. 2006; 21(1):89–98; doi: 10.1016/j.clinbiomech.2005.08.002.
20. Cornwall MW, McPoil TG, Lebec M, Vicenzino B, Wilson J. Reliability of the modified Foot Posture Index. J Am Podiatr Med Assoc. 2008;98(1):7–13; doi: 10.7547/09 80007.
21. Morrison SC, Ferrari J. Inter-rater reliability of the Foot Posture Index (FPI-6) in the assessment of the paediatric foot. J Foot Ankle Res. 2009;2:26; doi: 10.1186/ 1757-1146-2-26.
22. Terada M, Wittwer AM, Gribble PA. Intra-rater and inter-rater reliability of the five image-based criteria of the Foot Posture Index-6. Int J Sports Phys Ther. 2014;9(2):187–194.
23. Carter K, Horvat M. Effect of taekwondo training on lower body strength and balance in young adults with Down syndrome. J Policy Pract Intellect Disabil. 2016;13(2): 165–172; doi: 10.1111/jppi.12164.
24. Alsalaheen B, Haines J, Yorke A, Broglio SP. Reliability and construct validity of limits of stability test in adolescents using a portable forceplate system. Arch Phys Med Rehab. 2015;96(12):2194–2200; doi: 10.1016/j.apmr. 2015.08.418.
25. Atik A, Ozyurek S. Flexible flatfoot. North Clin Istanb. 2014;1(1):57–64; doi: 10.14744/nci.2014.29292.
26. Alghadir AH, Anwer S, Sarkar B, Paul AK, Anwar D. Effect of 6-week retro or forward walking program on pain, functional disability, quadriceps muscle strength, and performance in individuals with knee osteoarthritis: a randomized controlled trial (retro-walking trial). BMC Musculoskelet Disord. 2019;20(1):159; doi: 10.1186/ s12891-019-2537-9.
27. Schoenfelder DP, Rubenstein LM. An exercise program to improve fall-related outcomes in elderly nursing home residents. Appl Nurs Res. 2004;17(1):21–31; doi: 10.1016/j.apnr.2003.10.008.
28. Loudon JK, Dolphino MR. Use of foot orthoses and calf stretching for individuals with medial tibial stress syndrome. Foot Ankle Spec. 2010;3(1):15–20; doi: 10.1177/ 1938640009355659.
29. Gajdosik RL, Vander Linden DW, Williams AK. Influence of age on length and passive elastic stiffness characteristics of the calf muscle-tendon unit of women. Phys Ther. 1999;79(9):827– 838; doi: 10.1093/PTJ/79.9.827.
30. Kurz MJ, Wilson TW, Arpin DJ. Stride-time variability and sensorimotor cortical activation during walking. Neuroimage. 2012;59(2):1602–1607; doi: 10.1016/j.neuroimage.2011.08.084.
31. Jafarnezhadgero AA, Fatollahi A, Amirzadeh N, Siahkouhian M, Granacher U. Ground reaction forces and muscle activity while walking on sand versus stable ground in individuals with pronated feet compared with healthy controls. PLoS One. 2019;14(9):e0223219; doi: 10.1371/journal.pone.0223219.
32. Rosenbaum D, Schubert C, Sterzing T. Does backward running train specific muscles? Comparison of EMG activity patterns in forward and backward treadmill running. J Biomech. 2012;45(1):S295; doi: 10.1016/S0021-9290(12)70296-8.
33. Masumoto K, Takasugi S-I, Hotta N, Fujishima K, Iwamoto Y. A comparison of muscle activity and heart rate response during backward and forward walking on an underwater treadmill. Gait Posture. 2007;25(2):222–228; doi: 10.1016/j.gaitpost.2006.03.013.
34. Jansen K, De Groote F, Massaad F, Meyns P, Duysens J, Jonkers I. Similar muscles contribute to horizontal and vertical acceleration of center of mass in forward and backward walking: implications for neural control. J Neurophysiol. 2012;107(12):3385–3396; doi: 10.1152/ jn.01156.2011.
35. Grasso R, Bianchi L, Lacquaniti F. Motor patterns for human gait: backward versus forward locomotion. J Neurophysiol. 1998;80(4):1868–1885; doi: 10.1152/jn.1998. 80.4.1868.
36. Winter DA, Pluck N, Yang JF. Backward walking: a simple reversal of forward walking? J Mot Behav. 1989; 21(3):291–305; doi: 10.1080/00222895.1989.10735483.
37. Cipriani DJ, Armstrong CW, Gaul S. Backward walking at three levels of treadmill inclination: an electromyographic and kinematic analysis. J Orthop Sports Phys Ther. 1995;22(3):95–102; doi: 10.2519/jospt.1995.22.3.95.
38. Schneider C, Capaday C. Progressive adaptation of the soleus H-reflex with daily raining at walking backward. J Neurophysiol. 2003;89(2):648–656; doi: 10.1152/ jn.00403.2002.
39. Buldt AK, Allan JJ, Landorf KB, Menz HB. The relationship between foot posture and plantar pressure during walking in adults: a systematic review. Gait Posture. 2018;62:56–67; doi: 10.1016/j.gaitpost.2018.02.026.
40. Weng C-S, Wang J, Pan X-Y, Yu Z-Z, Wang G, Gao L-P, et al. Effectiveness of backward walking treadmill training in lower extremity function after stroke [in Chinese]. Zhonghua Yi Xue Za Zhi. 2006;86(37):2635–2638.
41. Takami A, Wakayama S. Effects of partial body weight support while training acute stroke patients to walk backwards on a treadmill – a controlled clinical trial using randomized allocation. J Phys Ther Sci. 2010;22(2):177–187; doi: 10.1589/jpts.22.177.
42. Abdou RGE, El-Negamy EH, Hendawy AS. Impact of backward gait training on mediolateral stability index in children with hemiparesis. J Med Sci Clin Res. 2014;2(8): 2042–2049.
43. Shibuya K, Kuboyama N, Tanaka J. Changes in ipsilateral motor cortex activity during a unilateral isometric finger task are dependent on the muscle contraction force. Physiol Meas. 2014;35(3):417–428; doi: 10.1088/0967-3334/35/3/417.
44. Boyas S, Remaud A, Bisson EJ, Cadieux S, Morel B, Bilodeau M. Impairment in postural control is greater when ankle plantarflexors and dorsiflexors are fatigued simultaneously than when fatigued separately. Gait Posture. 2011;34(2):254–259; doi: 10.1016/j.gaitpost.2011. 05.009.
45. Hoogkamer W, Massaad F, Jansen K, Bruijn SM, Duysens J. Selective bilateral activation of leg muscles after cutaneous nerve stimulation during backward walking. J Neurophysiol. 2012;108(7):1933–1941; doi: 10.1152/ jn.01159.2011.