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A Comparative Study on Speed and Pulse Rate Between Two Mechanisms with and without Windlass on Two Different Terrains: Randomised Cross-Over Design

Sedhuraja Malaichamy[1], Satyajit Kumbhar[2], Meghana Palkhade[3]

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ABSTRACT

Background: During the functional rehabilitation program (FRP), the significant difference in the speed and pulse rate between two walking mechanisms (with and without a windlass mechanism) on two different terrains, randomized cross-over trial.

Methods and materials: Twenty two students aged 18-22 years with normal physiques. Students in both groups were instructed to walk in bare foot with and without the windlass mechanism on floor and treadmill. The primary outcome was to increase the speed and decrease the time with the windlass mechanism in barefoot walking during the FRP. The secondary outcome was to reduce the effort by using the windlass mechanism in barefoot walking during the FRP.

Findings: The average time to complete 50 meters on the floor with a windlass mechanism is 30.7 seconds with a standard deviation of 0.91 seconds, whereas the average time without a windlass mechanism is 38.4 seconds with a standard deviation of 1.39 seconds. This difference in the mean is statistically significant (p <0.001). After walking, the average post-radial pulse rate with and without mechanism was 120.3 bpm and 131.4 bpm, with standard deviations of 2.87 bpm and 1.09 bpm, respectively. This difference in the mean is statistically significant (p <0.001). The average speed achieved for 120 seconds (2 minutes) with the windlass mechanism is 0.095 m/s with a standard deviation of 0.008 m/s, whereas the average speed achieved without the windlass mechanism is 0.066 m/s with a standard deviation of 0.007 m/s. This difference in the mean is statistically significant (p <0.001). After walking, the average post-radial pulse rate with and without mechanism was 129.8 bpm and 135.1 bpm, with standard deviations of 2.33 bpm and 3.34 bpm, respectively. This difference in the mean is statistically significant (p <0.001).

Interpretation: This study finds that there is an increase in speed with less effort (lesser pulse rate) while using a windlass mechanism on both terrains. This research study suggests that the windlass mechanism can be used during the FRP. BKL Walawalkar Hospital's Ethics Committee *(EC/NEW/INST/2020/320)* approved this study.

Keywords: Windlass Mechanism, Bare foot walking; Floor; Treadmill.

INTRODUCTION

When walking under typical circumstances, such as at one's preferred speed and step

Author Affiliation: [1]Professor, [2]Assistant Professor, [3] Associate Professor, SVJCT's BKL Walawalkar College of Physiotherapy, Ratnagiri 415606, Maharashtra, India.

Corresponding Author: Meghana Palkhade, Associate Professor, SVJCT's BKL Walawalkar College of Physiotherapy, Ratnagiri 415606, Maharashtra, India.

E-mail: msedhu2022@gmail.com

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length, the biomechanics of human gait are well understood. On the other hand, when moving about in daily life, people can and do walk at a variety of other speeds and step lengths. It may be useful to describe and ascertain the mechanics of locomotion by considering the variation in biomechanics across different gait conditions.[1] Walking speed (WS) is a valid, reliable, and sensitive measure appropriate for assessing and monitoring functional status and overall health in a wide range of populations.[2] Walking speed and endurance, such as short distance walking 10 meters walk test or 30 meter walk test and long distance walking 6 minutes walk test are used often to predict and assess rehabilitation outcomes.[3]

Barefoot walking is a natural pattern and movement, that improves awareness of foot positioning, increases the strength of feet and leg muscles, and boosts flexibility in the feet and ankles.[4,5] Barefoot functional rehabilitation exercises help in adapting the foot to different surfaces. These exercises help in strengthening certain smaller muscles of the foot located at the bottom which helps in decreasing the navicular drop and foot function scores. Thus reduction in both scores decreases the flat foot structure.[6] The evidence for walking barefoot is to reduce the knee adduction moment in patients with Osteoarthritis (OA), Stroke, and Parkinson's disease during rehabilitation.[7-9] Gait stability and variability parameter depend on age, footwear, and terrain of walking.[10]

The plantar fascia supports the foot during weight bearing activities, and the windlass mechanism is a mechanical model that characterizes this support and offers details on the biomechanical pressures exerted on the plantar fascia.[11] Typically used to move large objects like an anchor on a ship, a windlass is a horizontal cylinder that turns with a crank to draw on a chain or rope that wraps around the cylinder. The metatarsal bone and tarsal bone pull together and transform into a hard structure as the metatarsophalangeal joints (MTP) joints hyper extend, which causes the aponeurosis to become taut as it coils around the MTP, causing the longitudinal arch to rise.[12] Only in the case of dynamic loading did it become apparent that arch rise and toe dorsiflexion were related. These outcomes raise issues.[13]

Due to the advantages of this windlass mechanism in barefoot walking, this can be used during functional rehabilitation program. To determine the feasibility, this study was done on healthy volunteers. The purpose of this research study was to compare the speed and pulse rate of barefoot walking between with windlass and without windlass mechanism on Floor and Treadmill.

METHOD

2.1 Study Design

Randomized Cross-over design

2.2 Participants

The study protocol was approved by the institutional scientific and ethics committee. This research study was conducted at the SVJCT's BKL Walawalkar college of Physiotherapy campus, Sawarde, Maharashtra, India in October 2022. The total sample size for this study was 22 Physiotherapy students with a normal physique.

Intervention

Before the trial, students attended a session with a physiotherapist to learn how to effectively maintain the windlass mechanism in barefoot walking. The training protocol for the windlass mechanism and both terrains comprised the standardized educational and exercise components.

The inclusion criteria were age between 18 and 22 years. Students were monitored for normal gait in both genders including that with no recent injury or lower extremity pain from almost six months and they had no history of foot and ankle surgery in their lifetime. The exclusion criteria were, students having, pes cavus, pes planus, plantar fasciitis, musculoskeletal injuries from the last six months, any mental disorders, and limb length discrepancy.

The study was conducted in a spacious and ventilated room. Each student's height, weight, and BMI weremeasured. The students were demonstrated windlass walking by an Instructor for 50 meters walking on the floor and walking for 2 minutes (120 seconds) on Treadmill.

Based on the cross over design, Out of twenty two students, 11 underwent windlass mechanism followed by without windlass mechanism, and the remaining 11 students underwent without windlass mechanism followed by with windlass mechanism on both the terrains on the same day. Between these two mechanisms, a washout of four hours was given. After a reserve day, the study groups were reversed with two mechanisms (with and without windlass) on both terrains on the same day.

Before the trial, the floor was cleaned with proper sanitation by sweepers. The students were asked to clean and dry the foot to prevent any sweating which may cause them to slip on the floor during walking. The 11 students were asked to walk casually barefoot on the mosaic floor for 50 meters one by one. Before barefoot walking with the windlass mechanism, the student was asked to relax and calm down to settle down their pre-walking radial pulse and that was noted down. The student was advised to maintain the windlass mechanism throughout the 50 meters in length. After walking, the post-walking radial pulse was also recorded. The stopwatch was used to measure the time taken to complete 50 meters of walking. After the completion of barefoot walking, proper relaxation and refreshment had been given to students. Later, the remaining 11 students were asked to walk casually barefoot on the floor without the windlass mechanism according to the same guidelines that were followed with the windlass mechanism.

Before the trial, the treadmill was calibrated by a skilled biomedical engineer, and the students were instructed to walk on treadmill. The WESLO CADENCE 1020 treadmill was used for this study. The treadmill was placed on an even surface. The 20º of up inclination was maintained in treadmill. The length of the belt was 3 meters, and it took 120 seconds for 90 revolutions. The safety key clip was attached to the student's cloth to stop thetreadmill in any emergency. Each session consisted 2 minutes. Before barefoot walking with the windlass mechanism, the student was asked to relax and calm down to settle down their pre-walking radial pulse and that was noted down. The student was advised to walk casually and to maintain the windlass mechanism throughout the 2 minutes. After walking, the speed of the treadmill and the post-walking radial pulse of the student were recorded. After the completion of barefoot walking, proper relaxation and refreshment were given to students. Later, the remaining 11 students were asked to walk casually barefoot on a Treadmill without a windlass mechanism according to the same guidelines that were followed with the windlass mechanism.

Outcome measures

Primary Outcome

The primary outcome was to measure the speed with and without windlass mechanism in barefoot walking among healthy volunteers.

Secondary Outcome

The secondary outcome was to measure the effort by pulse rate between with and without windlass mechanism in barefoot walking among healthy volunteers.

Data analysis

Collected data were entered in excel software and analyzed using R software version 4.0.1. Continuous variables were presented as mean and standard deviation and categorical variables were presented as count and percent. Paired t-test was done to compare the means with and without windlass mechanism. $p < 0.05$ were considered

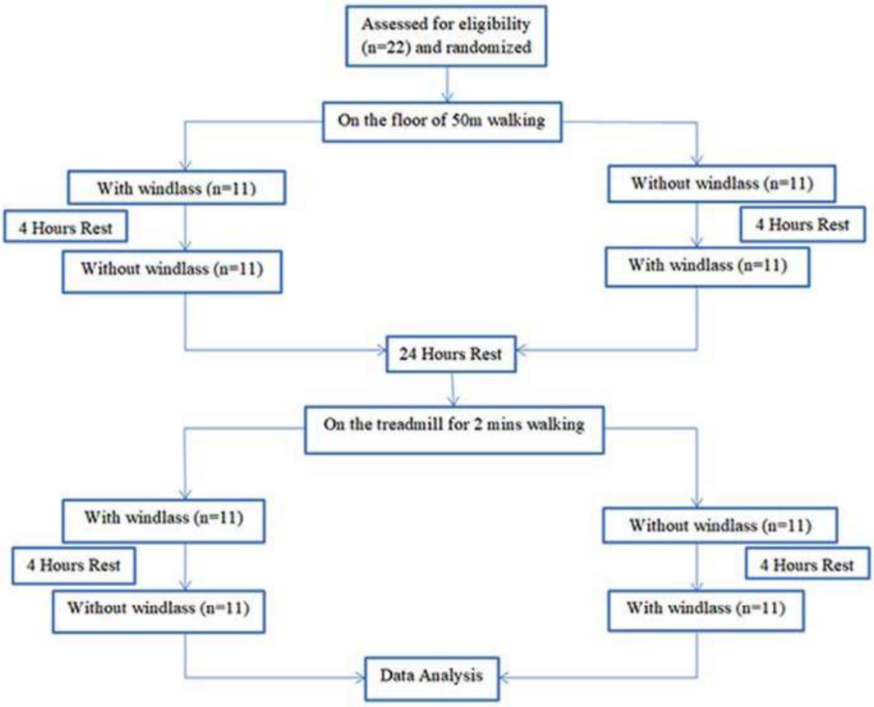

Fig. 1: Consort diagram illustrating the study design

statistically significant.

RESULTS

Out of 22 students, 5 male (22.7%) and 17 female (77.3%) students took part in this study. The average age was 20.04 with standard deviation 0f 0.82 years. Their average BMI was 21.4 with a standard deviation of 3.00.

Table 1: Descriptive for out come variables on the floor terrain

Variables	With Windlass		Without Windlass		p value
	Average	SD	Average	SD	
Time (Seconds)	30.7	0.91	38.4	1.39	< 0.001
Pre-walking Radial Pulse Rate	75.1	1.61	74.9	1.38	0.423
Post-walking Radial Pulse Rate	120.3	2.87	131.4	1.09	< 0.001

Table 1 provides values of outcome variables done on the floor. The average time taken to complete 50 meters with the windlass mechanism is 30.7 seconds with a standard deviation of 0.91 seconds, whereas the average time was 38.4 seconds without the windlass mechanism with a standard deviation of 1.39 seconds. This mean difference is statistically significant, $p < 0.001$. The Radial Pulse rate was measured before the commencement of walking, the average pre-radial pulse rate with and without the windlass mechanism were 75.1 bpm and 74.9 bpm with a respective standard deviation of 1.61 bpm and 1.38 bpm. This mean difference is statistically not significant, $p = 0.423$. The radial pulse rate was measured after the commencement of walking, the average post-radial pulse rate with and without mechanism was 120.3 bpm and 131.4 bpm with a respective standard deviation of 2.87 bpm and 1.09 bpm. This mean difference is statistically significant, $p < 0.001$.

Table 2: Descriptive for outcome variables on the treadmill terrain

Variables	with Windlass		without Windlass		p value
	Average	SD	Average	SD	
Speed (meter/second)	0.095	0.008	0.066	0.007	< 0.001
Pre-walking Radial Pulse Rate	78.5	1.96	77.6	2.11	0.329
Post-walking Radial Pulse Rate	129.8	2.33	135.1	3.34	< 0.001

Table 2 provides values of outcome variables done on the treadmill. The average speed achieved for 120 seconds (2 minutes) with the windlass mechanism is 0.095 m/s with a standard deviation of 0.008 m/s, whereas the average speed achieved was 0.066 m/s without the windlass mechanism with a standard deviation of 0.007 m/s. This mean difference is statistically significant, $p < 0.001$. The Radial Pulse rate was measured after the commencement of walking, the average pre-radial pulse rate with and without the windlass mechanism was 78.5 bpm and 77.6 bpm with a respective standard deviation of 1.96 bpm and 2.11 bpm. This mean difference is statistically not significant, $p = 0.329$. The radial pulse rate was measured after the commencement of walking, the average post-radial pulse rate with and without mechanism were 129.8 bpm and 135.1 bpm with a respective standard deviation of 2.33 bpm and 3.34 bpm. This mean difference is statistically significant, $p < 0.001$.

DISCUSSION

This randomized cross-over design is the first to compare the speed of barefoot walking and to compare the pre-walking radial pulse rate and post-walking radial pulse rate with and without the windlass mechanism on the Floor and Treadmill. In this study the students walked with windlass mechanism reached their destination promptly than without windlass mechanism and the Welte L *et al* stated that the people experience some difficulties walking quickly when receiving rehabilitation for stroke, Parkinson's disease, osteoarthritis, diabetes, and various sporting events. People would utilize a windlass mechanism to walk at that time to cover more ground in a shorter amount of time. Walking barefoot or in shoes is not as crucial as the foot striking pattern.[14] While walking with barefoot windlass mechanism, the students felt more push-off in their foot, Welte L *et al* briefed that when running barefoot, a forefoot striking (FFS) pattern gives the runner more sensory feedback from the foot ground contact as well as increased energy storage in the arch.[15] During windlass mechanism walking, the rearfoot strike was common among the pupils in this trial, Williams LR stated when compared to the prestance period of the rearfoot strike, the activity of the biceps femoris (BF) and gastrocnemius medialis (GM) increased (RFS). During the Pre-Stance Phase, the Tibialis Anterior (TA) declined more in the FFS than the RFS Pattern.[16]

The extension of metatarsal phalanges was common in windlass mechanism that naturally stretched the plantar fascia among youths and Chan CW *et al.* stated that the plantar fascia stretching was delayed by toe plantar flexion at foot striking, which likely alters how the stress was distributed among other arch tissues. After that, the windlass mechanism shortens the plantar fascia, which probably increases arch recoil during push-off.[17] In this trial, the young people felt that their foot was robusted with windlass mechanism while walking Nüesch C *et al.* that the rotational axis of the mid foot was changed by this windlass engagement, which likely positioned the arch spanning structures closer to their resting length and increased their compliance. This work offers new proof that the windlass and arch spring processes interact to control the amount of energy stored in the foot.[18] Due to the stretching of the plantar aponeurosis while walking with windlass mechanism, Mejia Cruz Y *et al.* stated that although the plantar aponeurosis was not a solid cable, it probably has some flexibility that influences how well the windlass mechanism works. Foot coupling was unaffected by arch structure, indicating that static arch height or arch flexibility.[19]

The speed of the gait was increased while walking with windlass mechanism in this study and Rose DK *et al.* stated that with up to 36 sessions of locomotor training or strength and balance exercises, participants who lived in communities generally exhibited gains in gait speed and walking distance at both 2 and 6 months following stroke.[20] This study took place indoor environment and Leppä Het al concluded that when environmental enablers for outdoor mobility are lost (during COVID-19), older individuals who perceive walking difficulty may be at risk of becoming house bound and should be the focus of interventions.[21] Through this study, the speed of walking was achieved with low radial pulse rate in windlass walking mechanism Nascimento LR *et al.* finalized that the benefits achieved by equivalent doses of center based exercises after stroke are anticipated to be comparable to the effects of home based prescribed exercises on walking speed, balance, mobility, and participation.[22]

In this study, the students experienced the tension in the plantar aponeurosis while walking with windlass mechanism and Caravaggi P *et al.* suggested that subjects' early stance phase plantar aponeurosis (PA) tension was considerably higher than the rest (p <0.01), supporting the PA-preloading hypothesis. From medial to lateral, the PA slips' maximum elongation and preloading are both reduced.[23] In this trial, while extension of all meta tarsal phalanges joint in windlass mechanism pupils recognized more movement at their foot and Manfredi-Márquez MJ *et al.* stated that according to kinematic analysis, the more extension there is, the more movement will be produced. The more distant a structure is from the 1st Metatarsal Phalangeal Joint (MTP), which affects the entire leg, the less impact it has. The impact couldn't be precisely measured since the kinematic system employed wasn't appropriated.[24] Walking with windlass mechanism on mosaic floor and treadmill was effective by more propulsion on students foot while Song S *et al.* briefed that walking on flexible feet used more energy than walking on rigid feet. According to preliminary findings, the compliance that the windlass mechanism embeds was not the source of the energy saved by its introduction. The windlass mechanism's ability to save energy was more closely tied to how it helped shorten the effective foot length when swinging than to how it helps with stance compliance.[25] Biomechanically, the MTP Joints were in extension during windlass mechanism and Kappel-Bargas *et al.* suggested that the first metatarsal phalangeal extension was passive when the windlass mechanism was activated.[26]

Students were not able to sustain their arch foot for prolong time during windlass mechanism when Gelber JR *et al.* concluded that the capacity to raise the arch from the toe-flat to an extended position was diminished in the Diabetes Mellitus and Peripheral Neuropathy (DMPN) severe and low groups.[27] Before this trial, the windlass mechanism was demonstrated and practised by students when Fuller EA *et al.* concluded that using mechanical engineering principles, the anatomy and mechanical operation of the foot's windlass mechanism were examined. Following an explanation, the free-body diagrams and force couple concepts were used to model the foot.[28] Windlass mechanism can be performed only in bare foot and Lin SC concluded that the right footwear for treating conditions like plantar fasciitis by efficiently lowering the windlass effect was the rocker sole shoe (RSS), which was effective footwear in minimizing the windlass effect regardless of the type of insole inserted.[29] In this study, healthy normal physique students were participated and Lucas R In contrast to individuals who had a working windlass mechanism, those without one had a more pronated foot posture, a lower dorsal arch height, and a broader mid foot breadth.[30]

In this study, on the floor, the average walking time was less with the windlass mechanism than without the windlass mechanism. On the treadmill, the average speed wasmore with the windlass mechanism than without the windlass mechanism. Moreover, the post-walking pulse was less with the windlass mechanism than without the windlass mechanism on both terrains.

Limitations

This study has a few limitations that there was on a smaller group of healthy volunteer students and this windlass mechanism was used a single time for this study.

CONCLUSION

This study finds that there was an increase in speed with less effort (lesser pulse rate) while using the windlass mechanism on both terrains. This finding suggests that the windlass mechanism can be used during the FRP. The windlass mechanism may help the patient and increase their cooperation with the Physiotherapist. Further studies are required to confirm this result with the patient population during the rehabilitation process.

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Conflict of Interest

There is no conflict of interest among the authors.

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