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Original Article

Physiotherapy Section

Effect of Rocker Soled Shoe Design on Walking Economy in Females with Pes Planus

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ABSTRACT

Introduction: The energy cost is increased during walking in pes planus condition whereas, energy cost during walking using rocker bottom shoes is debatable.

Aim: To determine the walking economy with rocker soled shoes, when compared with bare feet walking in females with pes planus over treadmill.

Materials and Methods: Seventeen collegiate flat footed females aged 18-25 years were recruited in accordance with inclusion and exclusion criteria. Subjects were asked to walk barefooted and with rocker soled shoes on treadmill for four minutes at a speed of 3.8 km/hour. Oxygen consumption (VO_2) was measured directly using PowerLab 8/35 data acquisition system with Lab Chart Pro (AD Instruments, Australia) one minute before walking, four minutes during walking and one minute after walking. Rating of Perceived Exertion (RPE) was taken after termination of walking.

Results: VO_2 during barefoot walking was significantly lower than rocker soled shoe walking during four-five minutes ($p<0.001$) and during recovery ($p=0.04$). RPE is significantly lower during barefoot walking than rocker soled shoe walking ($p<0.001$) over treadmill.

Conclusion: Oxygen consumption and RPE were increased during walking with rocker soled shoe design in comparison to bare feet walking over treadmill at same speed.

Keywords: Energy cost, Flat foot, Gait, Oxygen consumption, Rating of perceived exertion

INTRODUCTION

Pes planus (Flat foot) describes a pronated foot with flattening of the medial longitudinal arch. Flat feet (the lack of an arch while standing) are common in all age groups [1]. Physiological pes planus (flexible flatfoot) is a descriptive term for feet that have visually lowered Medial Longitudinal Arch (MLA) often in association with rear foot eversion [2]. MLA is maintained by contraction of muscles around the feet or strength of passive tissues or combination of both [2]. Due to problem or malalignment of MLA the function of muscles and joints of the ankle, knee, hip and lumbar region are affected [3]. Pes planus or relatively lower MLA have been linked with various conditions like metatarsal stress fractures [4], metatarsalgia [5], plantar fasciitis [6], achilles tendinitis [7], tibialis anterior inflammation [8] and being female [9]. Flat arched foot relies on additional muscular support during the gait cycle [10].

Rocker soles are rigid soles with a pivotal point placed strategically from which the foot rocks and rolls forward. They remove the propulsive phase of gait and alter both motion and force distribution patterns [11,12]. Rocker soles are most commonly prescribed external shoe modification, in case of diabetic neuropathy [13], insensitive foots [14], following ankle fusion [15] and undesirable pressure at the forefoot. Thus, reducing the chances of metatarsalgia, stress fracture, ulcers [12,16,17] and chronic Achilles tendinopathy by reduction in plantar flexion movement in the late stance phase of running and walking [18]. Rocker shoes have been shown to reduce excessive plantar pressure in the forefoot region during walking [11,19].

VO_2 (oxygen uptake) also referred to as pulmonary oxygen uptake, is a measure of how much oxygen your body is consuming at any given time. The efficacy of interventions for improvement of walking have used VO_2 recording in their measures. Therefore, energy expenditure during walking is determined by measuring VO_2 [20]. The energy cost and oxygen consumption get increased in flat foot conditions during walking [3]. Previous researches show that, energy cost during walking with rocker bottom shoes remains the same [21], gets increased [22] and gets decreased [23] when compared to standard shoes. Therefore, the effect of rocker soled shoe on oxygen consumption during walking in normal healthy individuals is not clear till date. It is assumed that biomechanical imbalances are expressed more in runners who suffered from flat foot because of enhancement of forces which are sustained by body and thus, increasing the energy consumption in runners [24]. However, to the best of our knowledge, no research has been done to check energy cost of the walking with rocker soled shoe in pes planus condition.

Therefore, the purpose of the study was to determine the walking economy with rocker soled shoe as compared with bare feet walking in females with pes planus over treadmill. Simultaneously RPE would be recorded and compared to see the efficacy of rocker soled shoe by observing the alteration in oxygen consumption.

MATERIALS AND METHODS

It is an experimental study with crossover design since the same set of participants underwent testing on day one and on day two. Ethical clearance was taken from Institutional Ethical Committee of Jamia Millia Islamia, New Delhi, India. All subjects gave their informed consent to participate in the study after being explained about the procedure of the study and their rights as research subjects.

Sample size was determined using Software G. Power 3.15 taking effect size to be 1, alpha level to be 0.05 and power (1-beta) to be 0.80. Keeping in mind the prospect of drop outs, 17 subjects were found to be necessary.

Seventeen collegiate flat footed females aged 18-25 years with Body Mass Index (BMI) 18.5-24.9 kg/m^2 (if value of navicular height divided by truncated foot length was found to be lesser than 0.17, then it was considered to be flat foot) having no other musculoskeletal pathology of lower limb were recruited during the months of January-February, 2015 from Jamia Millia Islamia and Delhi University by convenience sampling.

Inclusion criteria:

- BMI: 18.5-24.9 kg/m^2;
- Age: 18-25 years;
- Measurements used to characterize the normal foot and flat foot (if value of navicular height divided by truncated foot length was found to be lesser than 0.17, then it was considered to be flat foot and vice-versa) [25];
- Absence of any musculoskeletal pathology of lower limb.

Exclusion criteria:

- Any neurological impairment or lower extremity orthopaedic deformity;
- limb length discrepancy or any gait abnormality;
- an injury that required surgery within six months of their participation;
- any cardio vascular conditions like coronary artery disease, atherosclerosis etc.

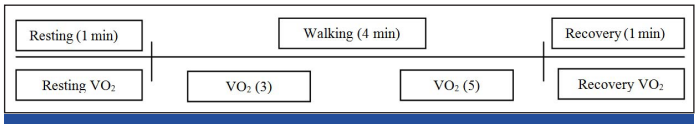
Procedure: Subject's weight and height were measured by digital weighing machine and stadiometer respectively. Also, navicular height (distance between the navicular tuberosity and the supporting surface) and truncated foot length (perpendicular distance between the first metatarsophalangeal joint and the posterior heel) were measured bilaterally for each subject using an inch-tape [25]. Subjects randomly performed any of the treadmill walking first i.e., either barefooted or with rocker soled shoes. Before going for testing, subjects were made to walk with rocker soled shoe over treadmill for two-three minutes to make them accustomized to treadmill. The actual testing was done 30 minutes after the accustomization. The washout period between the bare foot walking and rocker soled shoe walking was 24 hours.

The subjects were informed to sit on the chair with the back supported and arms rested on the thighs for one minute. Then subjects were asked to walk over treadmill for next four minutes with the speed of 3.8 km/hour followed by one minute of recovery, while sitting. Oxygen consumption (VO_2) was measured throughout the whole procedure of six minutes through custom software and hardware design {PL3508 PowerLab 8/35 Data Acquisition System with Lab Chart Pro (AD Instruments, Australia)}. The hardware included a respiratory mouth piece that consisted of a two-way valve mask secured by adjustable head gear. VO2 was calculated using a metabolic cart consisting of an oxygen analyser, a carbon dioxide analyser, a mixing chamber and a flow control pump. The cart was calibrated with gases of known concentration. Expired gas was directed by an expired gas hose to a spirometer and mixing chamber. VO_2 that was calculated during initial sitting was referred to as resting VO_2, oxygen consumption that was noted during two-three minute and four-five minute were referred to as VO_2 (3) and VO_2 (5) respectively and VO_2 taken while resting on the chair after termination of walking was said to be recovery VO_2 [Table/Fig-1]. Procedure of walking over treadmill was similar during both bare feet walking as well as rocker soled shoe walking.

The RPE was determined using the Borg scale [26]. A Borg scale was shown to subjects and they were asked to tell the amount of exertion they felt while walking with rocker soled shoe and when they walked bare feet. It was recorded at the end of walking on treadmill i.e., just before the recovery [Table/Fig-2].

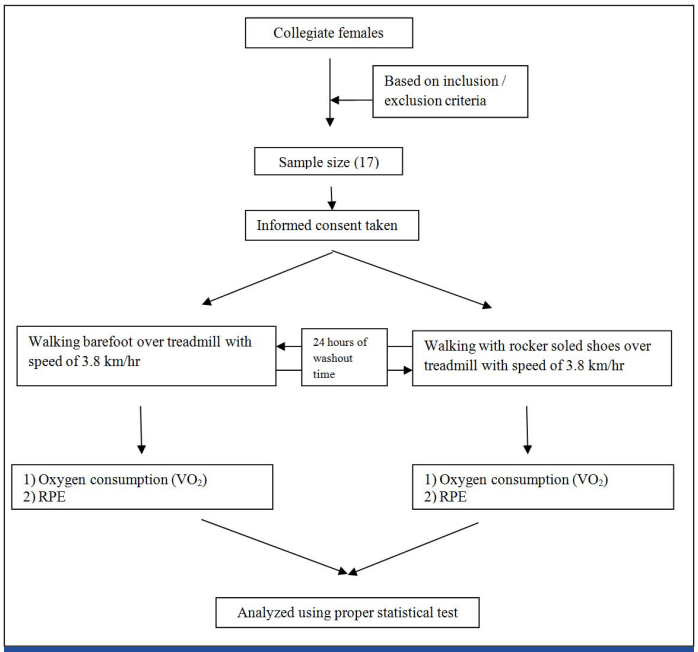
STATISTICAL ANALYSIS

The SPSS 21.0 version was used for data analysis. Shapiro-Wilk test was used to verify the normality of variables distribution scores. All the variables were normally distributed. Paired t-test was used for analysis of difference between the barefoot walking and rocker soled shoe walking. The confidence interval used was 95% with level of significance set at $p<0.05$.



[Table/Fig-1]: Estimation of VO_2.

RESULTS



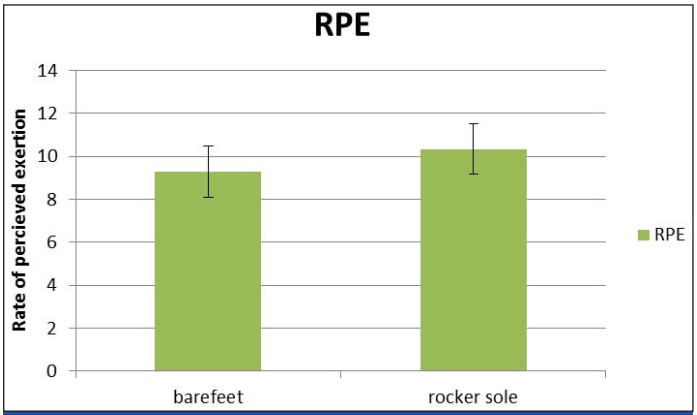
[Table/Fig-2]: Depiction of study protocol.

Measure	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
Mean	22.35	156.68	53.36	21.706
SD	2.06	4.176	5.66	1.8305

[Table/Fig-3]: Demographic characteristics of the subjects.
SD: Standard Deviation; BMI: Body Mass Index

Variable	Barefoot walking Mean (SD)	Rocker soled shoe walking Mean (SD)	t-value	p-value
Resting VO_2 (L/minute)	0.30 (0.05)	0.31 (0.05)	1.44	0.16
VO_2 (3) (L/minute)	0.55 (0.11)	0.59 (0.11)	2.42	0.27
VO_2 (5) (L/minute)	0.73 (0.13)	0.83 (0.15)	4.78	<0.001*
Recovery VO_2(L/minute)	0.36 (0.07)	0.40 (0.09)	2.18	0.04*
RPE	9.29 (1.21)	10.35 (1.16)	5.27	<0.001*

[Table/Fig-4]: Comparison of oxygen cost when walking bare feet and with rocker soled shoe design.
Results of paired t-tests; SD: Standard Deviation; VO_2 (3): Oxygen consumption between two-three minutes; VO_2 (5): Oxygen consumption between four-five minutes; *: Significant difference.



[Table/Fig-5]: Rating of perceived exertion (RPE) during walking bare feet in comparison to walking with rocker soled shoe design.

Results are reported in mean and Standard Deviation (SD), unless otherwise indicated. [Table/Fig-3] shows the age, height, weight and BMI characteristics of participants.

Oxygen consumption: Paired t-test revealed no significance difference for resting VO_2 between bare feet walking and rocker soled shoe walking (p=0.16). Also oxygen consumption during two to three minutes showed no significant difference between barefoot walking and with rocker soled shoe walking (p=0.27). However, the oxygen consumption during barefoot walking was significantly lower than rocker soled shoe walking during four to five minutes minute (p<0.001). Similarly Recovery VO_2 i.e., oxygen consumption during resting after walking barefoot was significant lesser than walking with rocker soled shoe (p=0.04) [Table/Fig-4].

RPE: Paired t-test revealed that there is significantly lowered RPE in barefoot walking when compared with the rocker soled shoe walking (p<0.001) over treadmill [Table/Fig-5].

DISCUSSION

The present study investigated the oxygen consumption in females with pes planus during walking with rocker soled shoe in comparison to barefoot walking over treadmill. The result of the study suggest that, there is a significant increase in the amount of oxygen consumption during fourth to fifth minute of walking over treadmill with rocker soled shoe upon comparison with barefoot walking. Also, significant difference is noted in recovery oxygen consumption during fifth to sixth minute. RPE was also significantly increased during walking with rocker soled shoe design, when compared to barefoot walking. However, the oxygen consumption calculated during rest and during second to third minute of walking showed no significant difference between the two. Previous studies [21,23,27] have seen the effect of rocker sole on oxygen consumption in normal individuals. to the best of our knowledge, no research has been done to see oxygen consumption after using rocker soled shoe in individuals with pes planus and ours is the first attempt.

Although, plenty of researches have been done regarding the Electromyography (EMG) activity of lower limb muscles with rocker soled shoe, there is scarcity of researches done regarding the oxygen consumption. Few evidence suggest that oxygen consumption increases with walking on unstable surface [22] while others contradict it [21,23].

In our study, resting oxygen consumption between the bare feet and rocker soled shoe during treadmill walking did not show any significant difference probably because participants were the same and the conditions were also similar in which, they were made to sit barefooted or with rocker soled shoes. Also, oxygen consumption during two to three minutes increased upto 7%, when wearing rocker shoes but this increase was not significant. The reason may be because the speed of treadmill was maintained at 3.8 km/hour which is less, thus, the subjects would not have perceived the exertion to that level, so as to bring a significant change in oxygen consumption.

Oxygen consumption during four to five minutes of walking showed significant difference signifying enhanced oxygen consumption during walking with rocker soles. Results similar to our study were shown by Sobhani S et al., using rocker sole in female runners with normally arched feet [17]. They had shown 4.5% higher oxygen consumption during running; however, subjects in our study have shown 13.69% increase. The reason for increased oxygen consumption in our study could be attributed to the weight of rocker soled shoes. Previous studies have shown that adding 100 g weight to the shoes/feet would result in approximately 1% increase in VO_2 [28]. Thus, based on extra shoe weight, an average increase of 5.8% in VO_2 was expected as the weight of the rocker shoe was 290 g each. Our findings however, showed an average increase of 13.69% in VO_2 during four to five minutes of walking. This result supports the hypothesis that factors other than the shoe weight might play a role in walking economy.

Two other factors could have contributed to increased walking economy with rocker soled shoes namely, high speed of walking over treadmill and inexperience of participants to walk with rocker shoes. So, in order to negate them we kept the speed of the treadmill slow i.e., 3.8 km/hour and familiarized them with rocker soled shoe design five minutes prior to the actual measurement of VO_2.

Further reason for increase in oxygen consumption could be attributed to increase in EMG activity of lower limb muscles during walking with rocker soled shoe. Koyama K et al. had shown higher EMG activity for the lower limb muscles when walking with unstable shoes compared to walking with stable shoes [29]. Along with lower limb muscles the increased activity of trunk muscles might have contributed to the increase in oxygen consumption which could have been occurred because of change in biomechanics while walking with rocker soled shoes.

Rocker shoes have different biomechanical characteristics. Koyama K et al., had shown that wearing unstable shoe increases the step length as well [29]. Gordan KE et al., had concluded that, step length is extended by 20% while walking at a constant speed, the mechanical work of ankle joint is increased, the vertical movement of the centre of mass is increased by 24% and metabolic power is increased by 36% [30]. So, the reason of increased oxygen consumption during walking with rocker soled shoe might have been due to alteration in step length and because of subsequent change in the above mentioned factors.

Also, the recovery VO_2 was higher in barefoot walking when compared with rocker soled shoe walking due to already high oxygen consumption during walking. The time taken to get recovered is same, due to same individual gone through both the procedure.

The present study has also shown significant increase in RPE, after termination of walking over treadmill in the females with pes planus in comparison to those walking barefoot. It was found to be increased by 11% though according to the scale, it was light only as they are walking at slow constant speed. Gjovaag T et al., reported that while wearing unstable shoes, RPE was increased only at fastest walking speed with a 10% inclination of treadmill [31] whereas Koyama K et al., had observed little change in RPE, despite the significant increase in VO_2 while walking with unstable shoes [29]. Our results were in accordance with Gjovaag TF et al., however, the increase in RPE in our study was observed at slower speed walking. The reason can be the population taken in our study i.e., flat feet females [31]. Also, the population was untrained, not having much treadmill walking experience so, the increase was much evident in them.

Clinical relevance of the study: Since oxygen consumption increases in rocker soled shoe design in individuals with pes planus in comparison to those walking bare feet at same speed, it can be an alternative to gym and can be used by athletes to reduce weight in weight category sports such as wrestling, gymnastics and boxing; also by non-athletic population. Also, rocker soled shoes can be used for muscular strengthening and balance training in athletes because it challenges the muscles more as they need to adapt to the unstable supporting surface. Although, bare feet walking involves lesser economy and provides with better proprioception and less internal injuries but, it increases the chances of external injuries, hence, it is not preferred.

LIMITATION

Although, significant results have been obtained from this research. There are few limitations associated with this study. Firstly, the sample size was very less, thus, the results need to be exercised with caution. Secondly, only young collegiate females were selected for this study so the results cannot be generalized to a larger population. Also, the treadmill speed was slow and constant and we

have not observed oxygen consumption at varying speeds. Future researchers are encouraged to conduct more and more researches in this area by overcoming the limitations and will add more to the body of literature.

CONCLUSION

The present study concludes that, the oxygen consumption and rating of perceived exertion were increased during walking with rocker soled shoe design in comparison to bare feet walking over treadmill at same speed.

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