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Original Research

Comparison of Oxygen and Energy Consumption between Running with Researcher-Made Beach Simulator Shoes and Sports Shoes with PU Soles

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ABSTRACT

Obese and overweight individuals strive to burn more calories per unit of time through walking, which is one of their main goals. The necessity of walking with shoes with the capability of burning more calories per unit of time compared to common shoes was very noticeable. This research aimed to compare oxygen and energy consumption between running with biomechanical beach simulator shoes and sports shoes with polyurethane soles in overweight women. In this semi-experimental and applied research, 16 overweight women were selected. A researcher-developed beach simulator shoe enhances muscle activation in the lower limbs and abdomen through two main mechanisms and by using the specialized knowledge of sports biomechanics. Consequently, this enhancement leads to increased oxygen and energy consumption compared to common walking shoes. The test protocol consisted of three stages with speeds of 3, 5, and 7 km/h on the treadmill, each stage lasting 3 minutes. The statistics related to oxygen and energy consumption were collected by Metamax gas analyzer and through calculations. The statistical method of Two-way analysis of variance test with repeated measures was used to test the hypotheses and analyze the data at a significance level of 0.05. The findings showed that the beach simulator shoes can significantly increase oxygen and energy consumption in overweight women (significant levels of 0.05 and 0.03 respectively). According to the findings of the present research, the beach simulator shoe was able to increase the oxygen and energy consumption of a person by using two layers of balls and hydrodynamics, compared to sports shoes with PU soles. Beach simulator shoes were able to burn more calories per unit of time than PU sports shoes.

Keywords: Beach Simulator Shoes, Energy Consumption, Oxygen Consumption, Overweight, Gas Analyzer

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INTRODUCTION

Walking is one of the basic and very important movement activities. Every normal person takes an average of 5000 steps per day [1]. People have different goals for running. Sometimes the goal is to consume less energy. In a running race, shoes are used to consume less energy and store and return energy from the sole of the shoe [2]. But the majority of people in parks and streets are looking for more energy consumption and calorie burning through walking. Thus, they should use shoes that facilitate the achievement of this goal. Many people resort to surgery and taking diet pills to get rid of excess fat every year, especially in their abdomen and sides, which sometimes has harmful side effects and most of them return to the previous state. But daily exercise and proper nutrition is the correct choice to avoid all these possible complications and harms, in addition to spending exorbitant costs. Therefore, you can use walking shoes that consume more energy and burn more calories per unit of time than other common shoes. To reduce the pressure applied on the foot, especially in the high-pressure points of patients with diabetes, neuropathy, and those with foot abnormalities, special shoes have been suggested [3-6]. Sports shoes have been developed with two primary objectives: minimizing the risk of injuries and optimizing athletic performance. Looking ahead, an emerging trend is the utilization of sports shoes as training tools [7]. In this regard, the effect of unstable Masai Barefoot Technology (MBT) shoes on muscle activity was tested [7-9] resulting in increased electrical activity and greater muscle involvement in the lower limbs.

The biomechanical shoe simulating the beach (BS) has a hydrodynamic middle layer containing liquid with a specific viscosity and a layer containing steel balls. These mechanisms promote muscle engagement across various stages of gait analysis, with the hydrodynamic layer enhancing and the steel ball layer promoting. Consequently, wearing BS shoes increases oxygen and energy consumption in individuals. This theoretical suggestion was supported by unpublished laboratory results that aimed to evaluate oxygen consumption during treadmill running in a majority (e.g., 50%) of the subjects. The results indicated that choosing soft and sticky materials during running requires greater effort compared to utilizing hard and elastic materials [10, 11]. After an hour of running on the beach, muscles in the legs, thighs, stomach, back, and hips tend to experience heightened fatigue and discomfort compared to running on flat surfaces. This can be attributed to the dynamic nature of the surface, which moves with each step, placing greater demands on these muscle groups. A separate study revealed that running on sand led to lower myoglobin levels in women's blood compared to running on grass, indicating reduced muscle damage [12]. This finding suggest that running on softer surfaces such as sand and its impact on muscle damage incurred during exercise. Based on the benefits of running on sand and its impact on muscle damage, we developed beach simulator shoes.

Based on this, the hydrodynamic layer containing a liquid with a specific composition and viscosity and a capsule made of elastic leather was embedded in the sole of the shoe. According to the results of scientific research, when walking on the sands of the beach with bare feet, more muscle effort is done in the body, and this leads to burning more calories in the body and double energy consumption. The paragraph you provided appears to have good academic writing and grammar. The findings indicated that the addition of 50 grams of extra load to sports shoes resulted in a significant increase in oxygen consumption, while it did not have a substantial impact on running economy. Running economy and maximum oxygen consumption are two indicators commonly used to predict the performance of runners [13-15]. A lower oxygen consumption during a movement activity required to achieve a certain speed indicates greater economy in the activity. It is worth noting that the weight of shoes can alter the distribution of mass in the lower limb, consequently affecting the distribution of mass and, consequently, the center of gravity of the lower limb.
Among the previous research that investigated the effect of weight gain on energy consumption, Federik [16] reported that increased weight at some points which have a greater distance from the center of gravity of the whole body may cause a further increase in energy consumption and energy cost. In a comparison of energy expenditure between adding weight to military boots and adding weight to bags attached to the waist, Russell and Belding [17] observed that adding weight to shoes increased the energy expenditure by four times compared to adding the same weight to the waist. Research has shown that increasing the weight of shoes at an average running speed increases oxygen consumption so that for every hundred grams added to the weight of shoes, there is a one percent increase in oxygen consumption [18, 19]. The purpose of this

research was to compare oxygen and energy consumption between the use of BS shoes and sports shoes with polyurethane (PU) soles in overweight women.

MATERIAL AND METHODS

In this study, a semi-experimental and applied research design with a counterbalanced design was utilized. The determination of the sample size was based on G∗Power analysis, which ensured that the sample size would be adequate for detecting at least a medium effect size. The parameters used in the analysis were an effect size of $f = 0.4$, a significance level $\alpha = 0.05$, and a power of $1\text{-}\beta = 0.80$. As a result, a total of 16 overweight female students from Shahid Bahonar University of Kerman were selected to participate in the study. Their demographic characteristics were as follows: age (mean ± standard deviation) of 30.50 ± 5.13 years, height of 166.24 ± 11.51 cm, body weight of 78.63 ± 12.15 kg, and body mass index of 27.45 ± 2.24. Prior to their participation, the selected participants provided their informed consent by completing a personal information registration form and a physical health questionnaire. For this research, the approval of Ethics Committee No.: IR.UK.REC.1401.014 was obtained from Shahid Bahonar University of Kerman, Kerman, Iran. These people did not engage in regular sports exercise throughout the week, and they were free from any deformities, injuries, or diseases. According to the definition provided by the American College of Sports Medicine (ACSM), lack of physical activity refers to not having participated in at least 30 minutes of physical activity, with an intensity ranging from 40% to 60% of maximum aerobic capacity, on at least three days per week within the past three months [20].

A layer of steel balls was incorporated in the heel section of the custom-made shoe used in the study. The combined mass of the steel balls was 280 grams, and this load was uniformly applied to all participants. The purpose of adding this load to the heel was to increase muscle engagement in the lower limbs and abdomen during the heel off and swing stages. Furthermore, the hydrodynamic layer situated in the middle section of the shoe's sole plays a crucial role. Enclosed within a specially formulated jelly substance, this layer is covered with elastic leather texture. During the push-off phase, this layer facilitates toe movement, enabling the required support and causing increased muscle tension. However, it may also introduce instability, necessitating the exertion of muscular power to maintain balance. Consequently, evaluating and documenting the impact of incorporating elastic leather into the material, which reduces pressure on the foot sole and enhances the contact surface, is imperative and warrants laboratory testing. Both shoes tested were of the same shape and made of the same material, and all the features were completely similar. The only difference was the presence of hydrodynamic and ball layers in the beach simulator shoes.

Formula 1. $$P = \frac{F}{A}$$

Fig. 1. Beach simulator shoes.

The current research design employed a counterbalanced approach, as demonstrated in Table 1, to mitigate the impact of potentially confounding variables such as learning and individual differences. This involved randomly dividing the 16 participants into two sub-groups, each consisting of eight individuals. Across two non-consecutive testing days, both sub-groups engaged in walking activities while wearing both types of shoes as presented in Table 1. Consequently, all participants walked with both the BS shoes and the sports shoes with PU soles in accordance with their assigned task during the experiment.

Table 1. Testing schedule for subjects with BS shoes and sports shoes with PU soles

	First day				**Second day**			
Sub-Group	Shoes	Walking for Adaptation	Warm-Up on Treadmill	Gas Analyzer on Treadmill	Shoes	Walking for Adaptation	Warm-Up on Treadmill	Gas Analyzer on Treadmill
1 (8 People)	**BS**	+	+	+	**PU**	+	+	+
2 (8 People)	**PU**	+	+	+	**BS**	+	+	+

(+) denotes activity included

(BS) beach simulated shoes

(PU) sports shoes with polyurethane soles

To adapt the subjects to the shoes, they were asked to walk freely with the new shoes for about 5 minutes. The heart rate sensor was installed on the subject's chest and the mask of the gas analyzer was installed, and after 3 minutes of warming up and getting familiar with walking on the treadmill, the speed of the treadmill was increased from zero to three kilometers per hour [21]. The speed of the treadmill reached 3 km/h and lasted for 3 minutes at the end of the warm-up phase and the beginning of the first phase [21].

The second stage started immediately by increasing the speed of the conveyor belt to 5 km/h and it was completed after 3 minutes. Then, the third stage was performed with a speed of 7 km/h and a duration of 3 minutes. After that, the cooling or recycling stage was performed for 3 minutes by reducing the speed and slope of the machine. It is noteworthy that the slope of the treadmill was +3% in all three stages [21]. To check the changes in oxygen and energy consumption in the total protocol, the oxygen consumption in the last two minutes of all subjects was selected for all three speeds of 3, 5, and 7 km/h. As a result, one column of oxygen consumption data was obtained for each shoe. By comparing the oxygen consumption of the entire test period in each shoe, we were able to see the effect of using each shoe on the rate of changes in oxygen consumption. The energy consumption rate was also obtained through the average heart rate of the people, separated by speed and according to the number of calories burned (formula 2). The normality of the gas analyzer output data was obtained through the Kolmogorov-Smirnov test, and the statistical method of Two-way analysis of variance test with repeated measures was used after ensuring the normality of the data distribution to analyze the data and test the hypotheses. Calculation of calories burned during non-maximal exercise (no VO2 MAX) - only for women [33]:

Formula 2. $$CB = T * (0.4472 * H – 0.1263 * W + 0.074 * A – 20.4022)/4.181$$

In order to measure oxygen and energy consumption, a Metamax gas analyzer manufactured in Germany (refer to Figure 2) was utilized. The device was connected to an Hp Cosmos Paragraphic tape recorder model (COS 10198), and the data from the device was received and saved using the system software, Metasoft Studio.

Figure 2. Running protocol using a treadmill and Metamax gas analyzer

The gas analyzer device was fully calibrated before each test, which included calibrating the volume with a three-liter syringe, air pressure control, and calibrating the electrode of oxygen and carbon dioxide gases with two ambient air and a mixture of calibrated gases that were combined with high accuracy (14.93% oxygen, 5.97% carbon dioxide, accuracy ± 1.5%). Before each test, two-point calibration of gases was done automatically [15].

A one-way analysis of variance (ANOVA) for repeated measures was performed using SPSS Statistics version 22 to compare the oxygen and energy consumption differences between overweight women wearing BS shoes and those wearing sports shoes with PU soles. Subsequently, paired t-tests were conducted to validate the observed significant differences between the two groups. A significance level of $p \leq 0.05$ was set to determine statistical significance.

RESULTS

As presented in Table 2, the utilization of BS shoes resulted in a significant increase in total oxygen consumption at speeds of 3, 5, and 7 km/h, as well as their average (13.16 ± 2.00 ml/min/kg, 18.77 ± 1.56 ml/min/kg, 25.59 ± 2.33 ml/min/kg, and 19.17 ± 6.22 ml/min/kg, respectively), compared to the use of sports shoes with PU soles at the same speeds (11.73 ± 1.59 ml/min/kg, 16.85 ± 1.47 ml/min/kg, 22.33 ± 1.82 ml/min/kg, and 16.97 ± 5.30 ml/min/kg, respectively) ($P \leq 0.001$).

Table 2. Paired t-test results for total oxygen consumption at different walking speeds while wearing different types of shoes.

Shoes	Total Oxygen Consumption (mil/min/kg)				p-value
	Speed 3 Km/h	Speed 5 Km/h	Speed 7 Km/h	Average	
PU	11.73 ± 1.59	16.85 ± 1.47	22.33 ± 1.82	16.97 ± 5.30	0.001*
BS	13.16 ± 2.00	18.77 ± 1.56	25.59 ± 2.33	19.17 ± 6.22	0.001*

*: significant ($P \leq 0.05$)

Furthermore, as outlined in Table 3, the utilization of BS shoes resulted in a significant increase in total energy consumption at speeds of 3, 5, and 7 km/h, as well as their average (13.06 ± 3.17 cal, 18.44 ± 3.99 cal, 24.56 ± 3.07 cal, and 18.68 ± 5.75 cal, respectively) compared to wearing sports shoes with PU soles at the same speeds (11.50 ± 3.20 cal, 15.13 ± 3.07 cal, 21.94 ± 3.31 cal, and 16.19 ± 5.30 cal, respectively) ($P \leq 0.001$).

Table 3. Paired t-test results for total energy consumption at different walking speeds while wearing different types of shoes.

Shoes	**Total Energy Consumption (cal)**				**p-value**
	Speed 3 Km/h	**Speed 5 Km/h**	**Speed 7 Km/h**	**Average**	
PU	11.50 ± 3.20	15.13 ± 3.07	21.94 ± 3.31	16.19 ± 5.30	0.001*
BS	13.06 ± 3.17	18.44 ± 3.99	24.56 ± 3.07	18.68 ± 5.75	0.001*

*: significant ($P \leq 0.05$)

DISCUSSION

The purpose of this research was to compare oxygen and energy consumption between the use of BS shoes and sports shoes with polyurethane (PU) soles in overweight women. Therefore, oxygen and energy consumption during running at three different speeds were compared between two types of shoes: beach simulator shoes and sports shoes with PU soles. The study focused on overweight women and found a significant difference in the results. The oxygen consumption of overweight women who used beach simulator shoes showed an overall increase of 2.20 ml/min compared to those who used sports shoes with PU soles. Additionally, there was a notable difference in energy consumption. Specifically, at a speed of 7 km/h, the average energy consumption was higher in the beach simulator shoes compared to the PU shoes. These findings indicate that the use of beach simulator shoes led to increased oxygen and energy consumption across all three different speeds and the average of the entire run. The research involved testing at speeds of 3, 5, and 7 km/h to simulate walking in parks and streets. The beach simulator shoes were designed to mimic running on sandy beaches, which resulted in higher energy expenditure for obese and overweight individuals compared to wearing regular shoes. This increased energy consumption can lead to burning more calories.

Previous studies have examined alterations in oxygen consumption during different activities [13, 19, 23, 26]. In the push-off phase of walking, the foot needs to displace the liquid and particles within the shoe to achieve a stable support level, which consequently involves greater muscle engagement in the lower limb. Introducing an uneven surface on the shoe sole aids in this process.

In the biomechanical shoe of the beach simulator, a layer with steel balls was used in the heel. Adding load on the heel was to cause more muscle involvement in the chain of muscles of the lower limbs and abdomen during the heel off and swing stages. Also, the mechanism of the hydrodynamic layer in the middle layer of the sole of the shoe, which is surrounded by a jelly substance with special composition and properties, with a cover of elastic leather texture. This layer was for the toes to move the jelly substance in the push off phase to reach the necessary support and this causes more muscle tension. Also, this layer may cause instability and force the person to use muscle power to maintain balance. As a result of the use of elastic leather surrounding the material, it reduces the pressure of the sole of the foot to increase the contact surface, which requires testing and documentation in the laboratory.

The use of hydrodynamic mechanisms to absorb loads is a common phenomenon in body tissues and joints. One practical example is the movement of liquid within the intervertebral disc, as well as the circulation of blood within the empty spaces in the heel bone [22]. Implementing this mechanism and leveraging the properties of liquids in shoe soles can contribute to walking safety [22]. When the foot makes contact with the ground, the movement of liquid within the intermediate layer of the shoe enables the absorption of viscous loads [22]. Instead of transferring the applied loads back to the foot, the energy is dissipated through the movement of fluid [22]. By employing a completely viscous sole, the contact surface area increases, resulting in reduced pressure on the sole of the foot, especially in high-pressure regions [22]. Researchers have considered various aspects in evaluating the effects of shoes to improve performance and prevent injury. Among them, we can mention the weight of the shoe [27,28], hardness [29,30], the material and structure of the shoe [27,30,31], and the geometric shape of the shoe [32]. By examining the difference in maximum oxygen consumption and energy consumption between the two mentioned shoe samples in each of the running speeds separately, even though there is a significant difference between them, it cannot be said that the movement system of the human body always shows a regular and systematic response to different levels of a variable that change in a regular manner [8-11]. This means that it cannot be expected that a gradual increase in movement speed, energy, and maximum oxygen consumption will increase with the same pattern (although the increase is evident, but not with a regular rhythm and pattern).

Further long-term tests should be conducted to investigate the potential benefits associated with the increased energy consumption observed during the use of beach simulator shoes. These benefits may include enhanced fat burning, weight loss, and blood sugar reduction in individuals with diabetes. The findings from such studies have the potential to serve as a powerful motivator for obese and overweight individuals, encouraging them to engage in regular walking and exercise as an alternative to relying on surgical procedures or weight loss pills. Beach simulator shoes can effectively promote daily exercise and instill hope and motivation in obese and overweight individuals, empowering them to prioritize physical activity and walking rather than resorting to surgery or weight loss medications.

The uneven surface created by the sand during walking continuously shifts beneath the feet. Consequently, applying pressure to the ground while running becomes more challenging than on a stable surface. However, this unevenness presents a positive aspect as it exerts additional pressure on various muscle groups within the body at specific intervals.

The primary objective of this study was to maximize calorie expenditure per unit of time through the utilization of beach simulator shoes. It is suggested to compare the distribution of plantar pressure, muscle force of lower limb muscles, and vertical ground reaction force between beach-simulating shoes and PU sports shoes. Additionally, a long-term study on obese and overweight individuals could investigate the amount of weight loss or reduction in fat mass achieved over an extended period using beach simulator shoes.

CONCLUSION

Walking with beach simulator shoes in a 9-minute running protocol affects average energy and maximum oxygen consumption. This means that we observed more calories burned per unit of time in beach simulator shoes than in PU sports shoes. Consuming more energy means consuming more of the body's energy resources, including glycogen (sugars) in muscles and liver and lipids (fats). Therefore, it is possible to imagine more fat burning in walking with beach simulator shoes than other common shoes, of course, by accurately measuring these factors in the next tests. And this can be a good motivation for obese and overweight people to encourage calorie burning and fat burning by exercising and walking using this model of shoes instead of using slimming pills and traumatic surgeries. This article is taken from the master's thesis on sports biomechanics. Hereby, we sincerely appreciate and thank all my dear professors at Shahid Bahonar University of Kerman who gave me their precious guidance and instruction.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors hereby declare their absence of any conflict of interest, thereby indicating their impartiality and lack of bias towards any particular entity or group.

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Conceptualization, methodology, FN, FM, MA-K; formal analysis, FN, FM,; investigation, FN, FM, MA-K; resources, FN, FM, MA-K; data curation, FN, FM, MA-K; writing-original draft preparation, FN, FM, MA-K; writing—review and editing, FN, MA-K; supervision, FM, MA-K; project administration, FN, FM, MA-K. All authors have read and agreed to the published version of the manuscript.

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مقایسه اکسیژن و انرژی مصرفی بین دویدن باکفش محقق ساخته شبیه ساز ساحل وکفش ورزشی با زیره PU

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چکیده

کالری سوزی بیشتر در واحد زمان یکی از اهداف افراد چاق و دارای اضافه وزن در پیاده روی است. نیاز به کفش هایی با قابلیت کالری سوزی بیشتر در واحد زمان نسبت به کفش های رایج کاملا احساس می شد. هدف از انجام این پژوهش مقایسه اکسیژن و انرژی مصرفی بین دویدن با کفش بیومکانیکی شبیه ساز ساحل و کفش ورزشی با زیره پلی اورتان در بانوان دارای اضافه وزن بود.

در تحقیق نیمه تجربی و کاربردی حاضر تعداد ۱۶ نفر خانم دارای اضافه وزن انتخاب شدند.کفش محقق ساخته شبیه ساز ساحل از طریق دو مکانیسم عمده و با بکارگیری دانش تخصصی علم بیومکانیک ورزشی باعث افزایش درگیری عضلانی اندام تحتانی و شکم می شود. لذا اکسیژن و انرژی مصرفی فرد را نسبت به کفش های پیاده روی رایج افزایش می دهد. پروتکل آزمون از سه مرحله با سرعت‌های ۳، ۵ و۷ کیلومتر بر ساعت روی تردمیل تشکیل شد که زمان هر مرحله ۳ دقیقه بود. اکسیژن و انرژی مصرفی به وسیله دستگاه گاز آنالیزور متامکس و از طریق محاسبات جمع‌آوری شد . روش آماری آزمون تحلیل واریانس دو طرفه با اندازه گیری مکرر جهت آزمون فرضیه ها و تجزیه و تحلیل داده‌ها در سطح معنی داری ۰/۰۵ استفاده شد.

یافته ها نشان داد کفش شبیه ساز ساحل توانسته اکسیژن و انرژی مصرفی را در خانم های دارای اضافه وزن بطور معناداری افزایش دهد (سطح معناداری به ترتیب ۰/۰۵ و ۰/۰۳). با توجه به یافته های تحقیق حاضر ، کفش شبیه ساز ساحل توانست به کمک دو لایه ساچمه ای و هیدرودینامیک خود در افزایش اکسیژن و انرژی مصرفی فرد نسبت به کفش ورزشی با زیره pu موثر عمل کند.

واژه های کلیدی :کفش شبیه ساز ساحل ، انرژی مصرفی ، اکسیژن مصرفی ، اضافه وزن، گاز آنالیزور