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Original Research

Comparison of Muscle Activity and Timing between a Custom Shoe with Hydrodynamic Mechanism and Regular Ethylene-Vinyl Acetate Shoe

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ABSTRACT

The importance of weight loss and fitness are considering as crucial issue during lifestyle. Therefore, wearing walking shoes can help to reduce plantar pressure in the high-risk areas of the foot. However, safety increasing of muscular activity and consequently energy consumption when using walking shoes are desirable. The aim of this study was to compare the muscle activity and timing between a custom shoe with hydrodynamic mechanism and regular Ethylene-Vinyl Acetate shoe. Twelve healthy men were selected for this quasi-experimental study. The custom hydrodynamic shoe was including outer sole with light Ethylene-Vinyl Acetate and also an inner silicon capsule was embedded in Ethylene-Vinyl Acetate sole. Moreover, there was some pathway with the special configuration on the silicon capsule to provide ways for flowing fluid. The shoemaker software version 2016 was used to make the final design of the shoe sole. Electrical muscle activity of the Gastrocnemius, Soleus, palmaris longus, and tibialis anterior activity at 1000Hz sampling rate were measured using the Myon electromyography system. Subjects randomly wore standard Ethylene-Vinyl Acetate sports shoes and hydrodynamic shoes and then go through the end of the pathway five times with self-selected speed. Onset and offset of muscle activation and an average of the smooth signal during the gait cycle were calculated and normalized based on maximum voluntary isometric contraction. The results indicated that gastrocnemius have significantly higher amplitude and the activation time when walking with the hydrodynamic shoe (P=0.02). Because of the important role of this muscle during walking, it seems that hydrodynamic shoe could an important effect for appropriately and safety increase walking economy.

Keywords: Hydrodynamic shoe, Ethylene-vinyl acetate, Electromyography, Walking.

Introduction

The Importance of weight loss and fitness are considering as crucial issues during lifestyle. In this way, exercise and physical activity are very important to be physically fit and in good weighting order. Among the various types of physical activities, it seems that walking is very popular because of its simplicity and safety especially in the adult and elderly people. But it has been shown that prolonged walking could be harmful to the lower limb, especially sole of the foot. Hereby, Muller et al. [1] reported that plantar pressure distribution could cause injury in three different ways in the plantar area when, applying extreme pressure, or exerting repetitive low pressure in a long time and may be due to the performing repetitive moderate pressure for a moderate period. Therefore, walking in a long period may cause different injuries for the sole or lower limb muscles. Researchers proposed that using of therapeutic footwear can reduce not only plantar pressure in the high-risk area of the foot [2-4], but also risk of walking-related injuries. Previous studies showed that the use of Ethylene-Vinyl Acetate (EVA) shoe, Rocker bottom shoe, and use of silicon for the sole of the shoe could effectively reduce the plantar pressure distribution [5-7]. Moreover, it has been indicated that the use of motion control shoes also could be very effective in lowering fatigue-related increases in mechanical loading following ground contact [8-10].

On the other hand, because of conservation energy mechanism in walking such as inverted pendulum [11, 12] the energy consumption during walking can be low, therefore only a long time walking will be effective for weight loosing. Therefore, people tend to perform more challenging and controversial activities for weight controlling. So, besides the safety, walking shoes should be able to increase muscular activity and consequently increase energy consumption (like walking on the sand) to become more effective for people looking for walking as safe and effective activities. For this purpose, the walking shoe must be designed to absorb energy deformation, to increase muscular activity and mechanical work during every step. Previous researchers tried to analysis shoes with different sole materials during walking [13-16]. These studies showed that the use of softer material could increase lower limb muscle activity. However, some researchers believed that the use of special material could reduce muscle activity during walking [17, 18].

In this study, the shoe with hydrodynamics mechanism was proposed that has special fluid in its sole to observe impact force by fully plastic deformation during heel contact to mid-stance following each step. Moreover, the muscular activity could change because of overcoming on the fluid viscosity and flow it toward the hindfoot. We hypnotized that using a fluid with certain viscosity that flows in the predetermined pathways cause to absorb deformation energy of shoe sole during ground contact, and consequently increase muscle activity and also time of muscle activity during late stance so that muscular effort and energy consumption during walking could be increase. Therefore, the purpose of this study was to compare the muscle activity and timing between a custom shoe with hydrodynamic mechanism and regular EVA shoe.

Material and Methods

Study design and Participants

Twelve healthy men were selected for this quasi-experimental study. Subjects had no history of muscle-skeletal impairments that may affect gait pattern. The average (SD) of age, weight, and height of players were (age: 24.9 ± 3.8 years, weight: 86± kg, height: 178.7 ± 6.4 cm), respectively. All subjects informed about the purpose of the study and the study approved by the local Ethics Committee.

Shoe design

The custom hydrodynamic shoe was including outer sole with light EVA and also an inner silicon capsule was embedded in EVA sole. Moreover, there was some pathway with the special configuration on the silicon capsule to provide ways for flowing fluid.

The fluid viscosity and capsule - pathways configuration was designed based on fluid flow in the pathways during heel contact, whereas moving the fluid into pathway could absorb contact energy. During pre-swing to the push-off phase of walking, the intrinsic and extrinsic muscles of foot and ankle have to work harder to push fluid in the hind-foot area to effectively create propulsion force on the ground during push off. The final design of the shoe sole includes an inner layer and outer layer was presented in Figure 1. The inner layer of the hydrodynamic shoe is a silicon firm of 3mm thickness with 97.8 GPa for hydrostatic load, and the outer layer has made of Polyurethane foam (PU) that is among the most common material in the walking and sports shoes. The shoemaker software version 2016 was used to make the final design of the shoe sole (Figure 1).

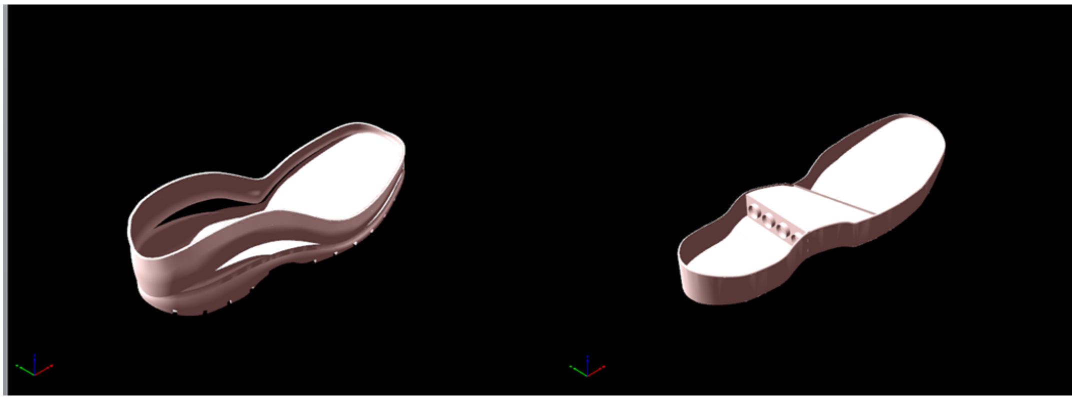

Figure 1: The 3D model of the hydrodynamic show includes two-layer; silicon inner layer (right) that contain special fluid in the predetermined pathway and outer EVA layer (left)

Test protocol

EMG data was measured using the Myon electromyography system. The EMG electrodes were placed on gastrocnemius, soleus, palmaris longus, and tibialis anterior muscles with 2 cm inter-electrode distance. Electrode placement was performed based on the SENIAM protocol and sampling rate selected at 1000Hz. Maximum voluntary isometric contraction (MVIC) for each muscle were measured during three trials.

Two shoes including standard EVA sports shoes and hydrodynamic shoes were used for this study. Subjects randomly wore the shoe without knowing about the shoe type. The subject walked through the pathway for 2 minutes for familiarity with the new situation. After the familiarity process, subjects walked through the end of the pathway five times with self-selected speed.

Data analysis

Every subject performed five trials while the first and last trials due to the familiarity and also fatigue effect ignored and the next three middle ones of these trials were selected for the analyzing process. EMG data was analyzed using by MATLAB Software (R2016a). A bandpass filter (15-500Hz) was used for data filtering. Onset and offset of muscle activation was calculated using Mean±2SD of baseline signal in 50 ms time window. Further, the data was rectified using butter worth low pass filter with a cut of the frequency of 15Hz. These protocols were done for the MVIC signal in the 200ms time window. Moreover, the average of the smooth signal during the gait cycle were calculated and normalized based on MVIC (MVIC%).

Statistical analysis

All statistics as mean and standard deviation used for descriptive analysis. Moreover, paired t-test was used for the detection of significant differences between hydrodynamic and EVA shoes. All statistics were carried out using the SPSS 20.0 statistical software package with an overall significance level set at $p < 0.05$.

Results

EMG

The mean, standard deviation, and Paired t-test of the normalized EMG data in all selected muscles, and also their activation time were presented in Table 1, Figure 2, and 3. The results of Table 1 showed although all muscles had higher EMG activity in the hydrodynamic shoe as compare to other one, however, it was significant only for the gastrocnemius muscle($P<0.05$). The results of Table 1 also indicated that the gastrocnemius muscle had significantly higher activation time in the hydrodynamic shoe ($P<0.05$).

Table1. The mean, standard deviation and independent t-test of the average rectified EMG (MVIC%) in all selected muscles

Muscle/variables	Shoes	Average of rectified EMG (MVIC%)	t-value	Sig	Time	t-value	Sig
Gastrocnemius	EVA	16.54 (4.3)	3.4	0.02*	1.09 (0.22)	2.1	0.04*
	Hydrodynamic	17.61 (3.9)			1.3 (0.2)		
Soleus	EVA	20.52 (5.5)	0.19	0.85	1.23 (0.2)	0.34	0.73
	Hydrodynamic	20.66 (4.1)			1.26 (0.18)		
Proneus longus	EVA	20.03 (4)	0.45	0.64	1.2 (0.19)	1.2	0.23
	Hydrodynamic	20.41 (6.2)			1.3 (0.2)		
Tibialis anterior	EVA	21.46 (6.3)	1.3	0.3	1.28 (0.27)	0.04	0.96
	Hydrodynamic	22.49 (4.5)			1.21 (0.21)		

*significant differences

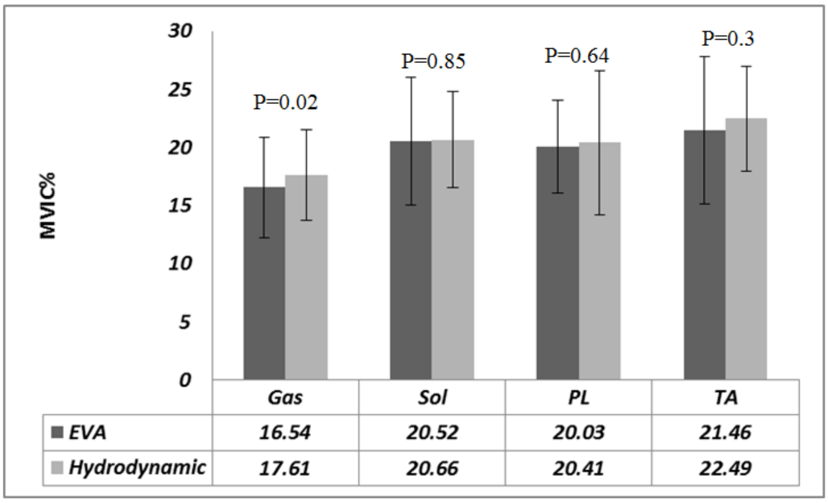

Figure 1. The mean and standard deviation of the normalized EMG data of all four muscles

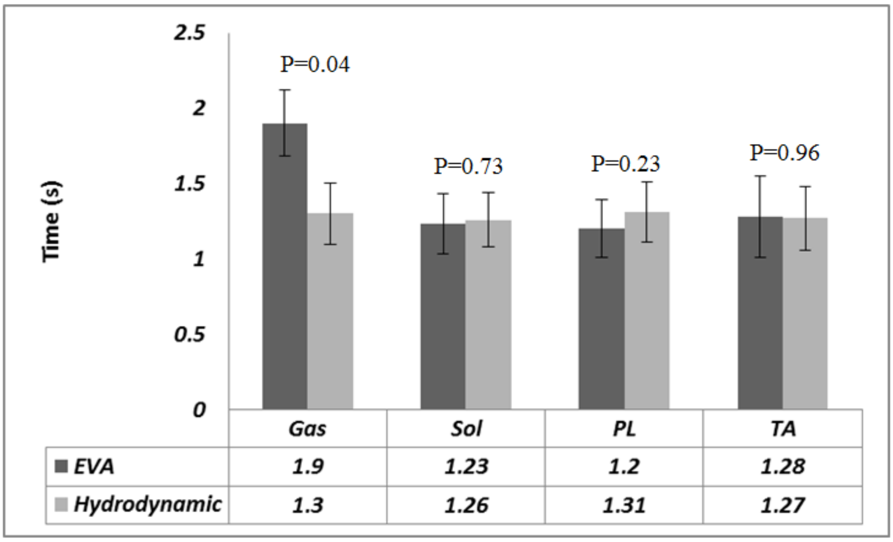

Figure 2. The mean and standard deviation of EMG activation of four muscles

Discussion

The aim of this study was to compare the muscle activity and timing between a shoe with hydrodynamic mechanism and regular EVA shoe. The results of this study showed that hydrodynamic shoe could significantly increase gastrocnemius activity and the activation time during walking. Increasing of the average of muscle activation and also its duration means that gastrocnemius fibers was recruited more and longer during walking. This result is in agreement with previous researchers that indicated the use of soft material in shoe sole could increase muscle activity during walking [10-13]. Moreover, as the same with previous studies that believed walking on the softer damping surface like sand could increase mechanical energy during walking [1, 2]. However, contrary to these results some researchers indicated that use of soft material could decrease muscle activation [17, 18].

The Importance of weight loss and fitness are considering as crucial issues during lifestyle. Among the various types of physical activities, it seems that walking is very popular because of its simplicity and safety especially in the adult people. Although, it seems that the mechanical efficiency of walking is very high [8, 9], on the other hand, because of conservation energy mechanism in walking such as inverted pendulum [11, 12] the energy consumption during walking can be low, therefore, walking is not considering as an appropriate activity for weight losing. It has been shown that prolonged walking could be harmful to the lower limb, especially sole of the foot. Hereby, Muller et al. [1] reported that plantar pressure distribution could cause injury in three different ways in the plantar area when, applying extreme pressure, or exerting repetitive low pressure in a long time and may be due to the performing repetitive moderate pressure for a moderate period. Therefore, walking in a long time for weight losses propose may cause different injuries for the foot and lower limb joints.

In this study, the custom shoes with a hydrodynamic mechanism were introduced. This shoe could absorb mechanical energy during walking from flowing fluid into special ways. This hydrodynamic shoe had special fluid in its sole with a viscosity of 10 times higher than the silicon layer with water into the sole of the shoe. A Silicon capsule had a special pathway that helps for fluid flowing during walking. During walking with a hydrodynamic shoe, following each step impact force absorbed by fully plastic deformation from fluid flowing, therefore muscular activity increased to overcome the fluid viscosity. The results of this study showed the significantly higher recruitment of the gastrocnemius fiber during walking. Because of the important role of this muscle during walking, it seems that hydrodynamic shoes could appropriately increase muscle activity and therefore the energy challenge during walking. The gastrocnemius muscle has special role during support and propulsive phases of the walking, whereas during the first half of the stance phase, it

controls forward leg swing, and during late stance, helps to produce propulsive force to push off [21]. The increase of the gastrocnemius activation and timing during walking can support the efficiency function of the hydrodynamic shoe. Because, walking with this shoe, the subject firstly should overcome the fluid and move fluid to another side of the shoe, then produce propulsive force for pushing-off, which causes increasing of activation and timing of this muscle. Similar researches on walking on soft material like sand or surface also showed that at this condition muscles most first try to deform underlying surface to make a stable platform for pushing-off, and then produce push-off force [13-16]. Therefore it seems that hydrodynamic shoes could increase muscle activation during walking as the same mechanisms used in walking on the sand or soft materials. It is important to note that based on previous research, the hydrodynamic shoe could effectively reduce plantar pressure on the high-risk region of the foot [22], therefore it seems that increasing of muscle activity and walking challenge could be completely safe and desirable.
It should be noted that since the focus of this research is more on walking, the results of this study as hydrodynamics effects of fluid due to differences between walking and running may not applicable for running situations.

Conclusion

The result of this study showed that the use of appropriate shoes as proposed in this study (hydrodynamic shoe) could turn walking into high demand activity. Like walking on the sand, hydrodynamic shoes also can cause deformation energy absorbed during walking, therefore, muscle activity and consequently mechanical energy during walking could increase. Therefore, it can be suggested to factories and people to use this hydrodynamic shoe for walking and help to turn walking into the high demand activity.

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چکیده فارسی

مقایسه فعالیت و زمان فعالیت عضلات بین کفش محقق ساخته با مکانیسم هیدرودینامیک و کفش فومی رایج

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کاهش ورزن در حال حاضر اهمیت روزافزونی پیدا کرده است. یکی از روش های رایج به منظور جلوگیری از اضافه وزن پیاده روی است. از این رو استفاده از کفش های مخصوص پیاده روی خیلی رواج پیدا کرده است. با این حال به دلیل اینکه پیاده روی فعالیت سنگینی نیست و انرژی مصرفی بالایی ندارد، کفشی که بتواند به طور ایمن انرژی مصرفی طی راه رفتن را بالا ببرد مورد نیاز جامعه است. هدف این مطالعه مقایسه فعالیت و زمان فعالیت بین کفش محقق ساخته با مکانیسم هیدرودینامیک وکفش EVA رایج است. در این مطالعه نیمه تجربی ۱۲ مرد سالم شرکت کردند. در این تحقیق کفشی مخصوص دارای مایع با ویسکوزیته معین در کف آن طراحی و مورد استفاده قرار گرفت که می توانست به دنبال گام برداری از طریق حرکت مایع بارهای اعمالی را کاهش دهد. کفش مدنظر با نرم افزار مخصوصی طراحی شد. به منظور مقایسه کفش هیدرودینامیک از کفش فومی EVA استفاده شد. سیستم الکترومایوگرافی میون برای اندازه گیری فعالیت عضلانی و زمانبندی عضلانی دوقلو، نعلی، نازک نی طویل و درشت نی قدامی در فرکانس ۱۰۰۰ هرتز مورد استفاده قرار گرفت. تحلیل الکترومایوگرافی با استفاده از نرم افزار متلب صورت گرفت و میانگین فعالیت هموار شده و زمان فعالیت عضله محسابه شد. نتایج این مطالعه نشان داد فعالیت تمامی عضلات با استفاده از کفش هیدرودینامیک افزایش داشته ولی تنها فعالیت و زمان فعالیت دوقلو معنادار بوده است ($P<0.05$). یافته های این مطالعه عملکرد کفش هیدرودینامیک را به تأیید رساندند به طوری که این کفش قادر است طی هرگام از طریق حرکت مایع انرژی تغییر شکل را جذب کرده و فعالیت عضلانی و متعاقباً انرژی راه رفتن را به طور ایمن افزایش دهد.

واژه‌های کلیدی: کفش هیدرودینامیک، کفش فومی، EMG، راه رفتن.