INFLUENCE OF ARCH SUPPORT INSOLE ON PEOPLE WITH FLATFOOT DURING UPHILL AND DOWNHILL WALKING

Yu-Ping Huang[1], Kwantae Kim[1], Chen-Yi SONG[2], Yat-Hon Chen[3], and Hsien-Te Peng[4]

Graduate Institute of Sport Coaching Science, Chinese Culture University, Taipei, Taiwan[1]
Department of Health Promotion and Gerontological Care, Taipei College of Maritime Technology, Taipei, Taiwan[2]
Global Action Inc.[3]
Department of Physical Education, Chinese Culture University, Taipei, Taiwan[4]

The purpose of this study was to investigate the effect of the arch support insole for people with flatfoot during uphill and downhill walking. Sixteen healthy collegiate students with flatfoot were recruited in this study. The heart rate, VO2max, and median frequency of surface EMG were recorded and analyzed in this study. Non-parametric Wilcoxon signed-rank test was used for statistics. The derived main results were outlined as follows: (a) $VO2_{max}$ had significantly decreased in arch support insole compare to flat foot insole during uphill and downhill walking; (b) arch support insole could reduce the fatigue of rectus femoris muscle during downhill walking which might be associated with the decreased $VO2_{max}$. The integrated research results could effectively be applied to the measurement of muscle fatigue.

KEY WORDS: oxygen uptake, fatigue, electromyography, low arch

INTRODUCTION: Uphill and downhill walking is regarded as a healthy recreational activity. Tjønna et al. (2013) indicated that the walking exercise has been proved to be beneficial for advantages such as reducing blood pressure, fasting glucose levels, and increases in $VO2_{max}$. Moreover, Werner, Lindquist, Bardeleben, & Hesse, (2007) indicated that uphill walking with an inclination of 2% to 8% and constant velocity of each gait on an inclined treadmill can improve the symmetry of the human body. Therefore, in order to relieve pressure at the workplace in the metropolis, more and more people are engaged in this exercise. However, people with foot issues such as flatfoot cannot really enjoy the walking.
People with flatfoot have foot arch support disability in which midfoot collapses in the medial longitudinal side (Kido et al., 2013). The function of midfoot acts as a shock absorber in the plantar while it allows the foot arch to maintain the appropriate elasticity to reduce the impact of the ground reaction force (GRF). However, people with flatfoot cannot sustain their body weight during long-term uphill and downhill walking.
The constant impact of the plantar by GRF, the probability of obtaining injuries such as heel pain or plantar fasciitis would increase (Jung et al., 2013). Previous studies have identified that function disorder in the foot could affect the lower back, hip extension, hip, knee, and ankle joint injuries (Harradine, Bevan, & Carter, 2006；Bird & Payne, 1999). Therefore, it is important to provide a solution such as arch support insoles for the prevention of lower limb injuries in flatfoot populations.
The purpose of this study was to investigate the effect of the arch support insole for people with flatfoot on the heart rate (HR), maximum oxygen uptake ($VO2_{max}$) and median frequency (MDF) of lower limb muscles during uphill and downhill walking. We hypothesised that there would be less HR, $VO2_{max}$ and less decrease of MDF of lower limb muscles in arch support insoles.

METHODS: Participants were 16 healthy collegiate students (aged: 18.3±0.7 years, height: 167.5±6.4 cm, weight: 65.1±14.4 kg) with flatfoot which was diagnosed with the arch index (AI) of 0.72±0.10 (Forriol & Pascual, 1990). All participants signed the informed consent and had no lower limb injuries and no surgical records in lower limb within the span of a year. Table 1 lists the anthropometry parameters of participants.

Table 1
Aanthropometry measurements of participants

Measurements	(N=16)
Age (y)	18.3±0.7
Height (cm)	167.5±6.4
Weight (kg)	65.1±14.4
Body mass index	23.2±4.7
Widest foot width (cm)	8.5±0.7
Narrowest foot width (cm)	6.1±1.1
Arch index	0.72±0.10

One day was scheduled to record each participant's footprint using a footprint device (Footdisc, Inc., Taipei, Taiwan). Then AI was calculated using the narrowest foot width divided by the widest foot width from the footprint. Another day was scheduled to do the formal experiment. Participants were instructed to perform 15-minute uphill and 15-minute downhill walking randomly in standardized foot wears (Maximizer16, Mizuno Taiwan Corporation, Taipei, Taiwan) with either a pair of arch support foot insole (Footdisc, Inc., Taipei, Taiwan) or a pair of flat insole (Maximizer16, Mizuno Taiwan Corporation, Taipei, Taiwan). The uphill and downhill walking were simulated walking on a ±9 degree inclined treadmill (XG-1812X, New noble sport equipment Co., Ltd., Ningbo, China) with the speed of 0.75 m/s (2.7 km/h)(Franz and Kram, 2012; Haight, Lerner, Board, & Browning, 2014).
A heart rate monitor (H7, Polar Electro Inc., Kempele, Finland) was utilized to supervise HR and a portable spiroergometry (Metamax 3B, Cortex, Leipzig, Germany) was utilized to measure the $VO2_{max}$. EMG data were collected using a Delsys system (Trigno wireless, Delsys, Massachusetts, USA) with 1000Hz sampling rate. Rectus femoris (RF), tibialis anterior (TA), bicep femoris (BF), and gastrocnemius (GAS) were measured.
The raw data of EMG signals were converted into MDF-time graph using EMGworks analysis software (Delsys, Inc., Massachusetts, USA) with 0.125 seconds window length and 0.0124 seconds overlap. Then the MDF-time graph was processed using curve fit calculation. The slope of the curve was calculated to present the decrease/increase MDF during uphill and downhill walking. The formula of the slope was Y_2-Y_1 divided by X_2-X_1 (where Y_1= first MDF value of the curve, Y_2= smallest or last MDF value of the curve, X_1= time of Y_1, X_2= time of Y_2). SPSS 18.0 (SPSS Science Inc, Chicago, Illinois) for Windows was used to calculate the statistics. Non-parametric Wilcoxon signed-rank test was used to compare differences between arch support insole and flat insole on HR, $VO2_{max}$, and the slope of MDF during uphill and downhill walking. The level of significance was set at $p < .05$.

RESULTS: Table 2 shows the parameters outcome during uphill and downhill walking. $VO2_{max}$ showed significant differences between arch support insole and flat insole during both uphill and downhill walking (arch support insole: 20.7±3.6 ml/min/kg, flat insole: 31.6±5.5 ml/min/kg, p<0.001 support insole: 10.9±2.3 ml/min/kg (insole), flat insole: 16.9±4.2 ml/min/kg, p<0.001 respectively). $VO2_{max}$ in arch support insole during both uphill and downhill walking were significantly smaller than that in flat insole based positive ranks. Moreover, the MDF slope of RF showed significant differences between arch support insole and flat insole during uphill and downhill walking. During uphill walking, the MDF slope of RF in arch support insole (-1.90±1.60 Hz/minute) was significantly smaller than that in flat insole (-0.83±1.10 Hz/minute) based on positive ranks, p=0.036. However, during downhill walking, the MDF slope of RF in flat (-6.56±23.07 Hz/minute) was significantly smaller than that in arch support insole (0.03 ±1.17 Hz/minute) during downhill walking based on negative ranks, p=0.023. There is no difference found in the HR and MDF slope of TA, BF, and GAS.

Table 2
Parameters outcome during uphill and downhill walking

	Uphill walking		Downhill walking	
	Arch support insole	Flat insole	Arch support insole	Flat insole
Heart Rate (bpm)	141.4±16.0	140.9±14.4	103.6±11.9	105.1±12.6
$VO2_{max}$* (ml/min/kg)	20.7±3.6[a]*	31.6±5.5[a]*	10.9±2.3[a]*	16.9±4.2[a]*
MDF slope of muscles				
Rectus femoris* (Hz/minute)	-1.90±1.60[a]*	-0.83±1.10[a]*	0.03 ±1.17[b]*	-6.56±23.07[b]*
Tibialis anterior (Hz/minute)	-1.12±1.67	-1.12 ±1.03	-1.43±1.84	-1.79±2.08
Bicep femoris (Hz/minute)	-1.23±1.73	-1.21±0.99	-0.79±1.57	-1.54±0.93
Gastrocnemius (Hz/minute)	-1.38±1.63	-1.03±1.25	-1.34±2.25	-2.01±1.72

*significant difference found between arch support insole and flat insole, $p<.05$; minus value of the MDF slope means the decrease of MDF; [a]: based positive ranks, [b]: based negative ranks

DISCUSSION: The primary findings of the present study indicated that the $VO2_{max}$ significantly decreased in arch support insole during both uphill and downhill walking and the decrease of MDF of rectus femoris was small just during downhill walking.

Wearing arch support insole could save people with flatfoot energy because $VO2_{max}$, which measured the highest values of oxygen uptake in the span of 15 -minute uphill and 15-minute downhill walking, decreased. Haykowsky et al., (2013) indicated that the high intensity of exercise would result in the significant increase of the $VO2_{max}$ to compare to the moderate intensity of exercise. In other words, $VO2_{max}$ could be regarded as the intensity index of the body loading. In the aspect of physiology, arch support insole could reduce the loading of human body. Therefore, people with flatfoot using the arch support insole may be able easily engaged in the recreational exercise of uphill and downhill walking. We suggested that the arch support insole might effectively reduce the exercise intensity which was caused by the impact of uphill and downhill walking.

Previous researchers indicated that an effective EMG characteristic analysis for the muscle fatigue detection was based on the median frequency which would be smaller as the muscle was fatigued (Thongpanja, Phinyomark, Phukpattaranont, & Limsakul, 2013; Allison & Fujiwara, 2002). The median frequency shift was resulted from the change of the conduction velocity (Solomonow et al., 1990) and change in the intra-muscular pH (Gerdle et al., 2000). In the current study, when participants wore the arch support insole, the significantly less decrease of median frequency was only found in rectus femoris muscle during downhill walking. But the outcome was contrary to that during uphill walking. It could be conjectured because of the different contraction type of rectus femoris during uphill and downhill walking. The rectus femoris in uphill walking was regarded as the concentric contraction while that in downhill walking was regarded as eccentric contraction. In general, the eccentric contraction was induced from more ground impact force compared to the concentric contraction. Previous researchers indicated that fast-twitch muscle fibers activation may be associated with more demand of injuries in eccentric contraction (Mchugh, Tyler, Greenberg, & Gleim, 2002). The arch support insole for people with flatfoot could reduce rectus femoris fatigue especially in downhill walking. Lastly, the phenomenon of rectus femoris fatigue might be associated with the decreased $VO2_{max}$ during uphill and downhill walking in the current study.

CONCLUSION: Wearing arch support insoles can benefit the uphill and downhill walking exercises for people with flatfoot because the oxygen uptake has been effectively decreased during uphill and downhill walking and there was less rectus femoris muscle fatigue during downhill walking.

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