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Muscle Activations of the Paraspinal Muscles in Different Types of Shoe during Walking

Miseung Kim[1)], Sumin Kim[1)], Seurim Kim[1)], Jinhyun Park, PT[2)], Dongwook Han, PhD, PT[1)]

[1)] *Department of Physical Therapy, College of Medical and Life Science, Silla University: 100 Silladaehakgil, Sasanggu, Busan, 617-736 Republic of Korea. TEL: +82 51-999-6238, FAX: +82 51-999-5176, E-mail: dwhan@silla.ac.kr*

[2)] *Department of Physical Therapy, College of Rehabilitation Science, Daegu University*

Abstract. [Purpose] This study researched the effect of different types of shoe on the muscles surrounding the cervical spine, the thoracic spine and the lumbar spine by analyzing muscle activation of the paravertabral muscle during walking on flat ground. [Subjects] The 28 subjects of this experiment were females in their 20s, with a foot size of 235–240 mm and a normal gait pattern, who had no foot deformities or muscle problems. [Methods] We selected three kinds of shoes sized 240 mm, and measured the muscle activation of the paraspinal muscles around C4, T12 and L3, and the trapezius and multifidus muscle. [Results] The muscle activations of all muscles differed significantly among the shoes. Especially, at the C4 paraspinal muscle and trapezius, the value of muscle activation induced by the flat shoes was the lower than those induced by the other shoes. The muscle activation induced by the functional walking shoes was significantly higher than that induced by the flat shoes at the C4 paraspinal muscle, and the muscle activations induced by the high-heel shoes were significantly higher than those induced by the other shoes in all of the muscles except for the L3 paraspinal muscle. [Conclusion] In view of these results, wearing high-heel shoes is not recommended for those who have spinal problems, and those who have cervical troubles should be advised to wear only flat shoes.

Key words: Flat shoes, Functional walking shoes, High-heel shoes

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INTRODUCTION

When we look at the original purpose of the shoe, it is clear that the primary concern was the safety and comfort of the foot while walking. While the shoe's function was the original focus[1)], it is now the aesthetic effect of shoes (i.e. high-heel shoes) that is increasingly of interest to the consumer[2, 3)]. Statistics show that 59% of women wearing high-heel shoes wear them for 1 to 8 hours a day[4)], while some wear them for more than 10 hours continuously[5)]. However, it is reported that wearing high-heel shoes can cause lumbar lordosis and other side effects[6)]. When shoes with a heel of more than 4–5 cm are worn, the person wearing them pushes the trunk backward so as not to fall forward, thereby increasing pressure on the lumbar spine and possibly triggering lower back pain as well[7)]. Although shoes were originally worn for the protection of a human body part, they are now ironically a cause of pain and deformity of the musculoskeletal system[8)]. In line with this, Lee et al. confirmed that the higher the heel height and the smaller the heel surface contacting the ground, the wider the sway of the center of body mass (CBM) and the bigger the weight loading on back muscles and the lower extremity, and this resulted in an unstable walking posture[9)]. Yoon et al. found that the higher the heel, the greater the activation of the soleus muscle of the lower extremity[10)].

As noted above, most studies have addressed the effect of heel height on the lower extremity, and the muscles of the lumbar region, and there is a lack of studies on how heel height affects the muscle activations of the cervical, thoracic, and lumbar region.

Therefore, this study researched the effect of flat shoes, functional walking shoes, and 7 cm high-heel shoes on the muscles surrounding the cervical spine, the thoracic spine and the lumbar spine by analyzing the muscle activations of the paravertabral muscles during walking on flat ground.

SUBJECTS AND METHODS

The 28 participants of this experiment were females in their 20s, with a foot size of 235–240 mm and a normal gait pattern, who had no foot deformities or muscle problems. All candidates were informed of the purpose of the study and its significance before their participation and voluntarily agreed to join the experiment. We selected three kinds of shoes sized 240 mm: flat shoes having no heels, similar to the naked foot condition; functional walking shoes designed for exercise and body alignment featuring three sole sections conducive to "Masai-style walking"; and high-heel shoes with a 7-cm heel, which are aesthetically preferred by 38.5% of women aged 19–23 and 30.8% of women aged 24–27, according to Yoo et al.[11)]. To measure the muscle activations

Table 1. Comparison of the muscle activities induced by the different kinds of shoes

Variations	Standing	Flat shoes	Functional walking shoes	High heeled shoes
C4 paraspinalis*	5.72 ± 8.20	8.20 ± 3.36	11.11 ± 6.87†	10.25 ± 4.20†
Upper trapezius*	8.20 ± 6.68	10.52 ± 7.50	11.89 ± 7.35†	13.98 ± 8.15†‡
T12 paraspinalis*	9.99 ± 4.99	17.80 ± 10.33	16.90 ± 9.56	25.02 ± 15.17‡≠
L3 paraspinalis*	18.35 ± 5.83	26.71 ± 14.84	29.26 ± 10.80	29.29 ± 10.12
Lumbar Multifidus*	21.10 ± 7.77	37.38 ± 17.70	36.85 ± 15.13	41.87 ± 18.36‡≠

(unit: %MVIC). Mean ± SD, * Statistically significant, $p<0.05$. † Flat shoes< Functional walking shoes. ‡ Flat shoes< High-heel shoes ≠ Functional shoes < High-heel shoes

of the cervical, thoracic and lumbar spine muscles during walking, EMG (FlexCompInfiniti EMG, Thought-tech) was used. To reduce measurement errors at the site of the EMG electrodes, foreign substances like hairs were shaved off and the area was then cleansed with alcohol. In addition, the connecting wires were firmly attached to the bodies of the participants so that noise would not interfere with the EMG signals during walking[12]. The following muscles were selected: the paraspinal muscle around C4 and the upper trapezius of the cervical spine muscle (to measure paraspinal muscle activation); the paraspinal muscle around T12 of the thoracic spine muscle; the paraspinal muscle and the multifidus muscle around L3 of the lumbar spine muscle. As Jung suggested, an EMG electrode was attached to the stomach muscle where it is most activated[13]. First, the EMG electrodes were attached to the muscles surrounding the spine and the maximum EMG value of each muscle was measured while the subjects performed maximal voluntary isometric contraction (MVIC). The measurements recorded during walking were normalized to MVIC and the unit of the normalized measure %MVIC, which was calculated as follows: $\%MVIC = EMG_m / EMG_{max} \times 100\%$, where %MVIC is the value of the normalized EMG, EMG_m is the measured value of EMG during walking, and EMG_{max} is the maximum value of EMG, for each muscle. After taking a rest until their breathing became stable, the participants first walked wearing the flat shoes, then in the functional walking shoes made of soft material and lastly in 7 cm high-heel shoes. A rest between each walk with the different shoes was imposed until participants' respiration rate returned to a normal rate. For each type of shoe, the EMG signal of the five muscles was first measured while the participants were standing on a hard flat surface and was then measured again while they walked 10 meters. Each measurement was carried out three times and averaged for the analysis. After confirming the normality of the data distribution with the Shapiro-Wilk normality test, we conducted parametric tests. Each participant wore each different type of shoe and the activation of each muscle was measured during both standing and walking. For this reason, we used repeated measures ANOVA and to examine differences in muscle activation among the types of shoe. We also carried out the paired t-test in order to examine differences in the values of muscle activation between each type of shoe. We used the statistical program SPSWIN (ver. 19.0) for statistical analysis and a significance level of $\alpha=0.05$.

RESULTS

The muscle activation of the C4 paraspinal muscle in standing position was 5.72%MVIC and it differed with the type of shoe. With flat shoes, the value was 8.20%MVIC; with functional walking shoes, it was 11.11%MVIC; and with high-heel shoes, it was 10.25%MVIC ($p<0.05$). It is notable that the value of muscle activation was not so different between the functional walking shoes and high-heel shoes, but was considerably lower than that of flat shoes. The muscle activation of the upper trapezius muscle was 8.20%MVIC while standing, 10.52%MVIC while wearing flat shoes, 11.89%MVIC while wearing functional shoes, and 13.98%MVIC in high-heel shoes ($p<0.05$). The value of muscle activation was lowest when wearing flat shoes, followed by functional shoes and then high-heel shoes. The measurements of T12 paraspinal muscle activation were as follows: standing position, 9.99%MVIC; flat shoes, 17.80%MVIC; functional shoes, 16.90%MVIC; high-heel shoes, 25.02%MVIC ($p<0.05$). While there was little difference between flat shoes and functional shoes, the muscle activation induced by the high-heel shoes was considerably higher. As for muscle activation of the L3 paraspinal muscle, the average value was 18.35%MVIC in the standing position, 26.71%MVIC while walking in flat shoes, 29.26%MVIC while walking in functional walking shoes, and 29.29%MVIC while walking in high-heel shoes. In this instance, there were no significant differences among the types of shoe. For the muscle activation of the lumbar multifidus muscle, the standing position value was 21.10%MVIC, the flat shoes value was 37.38%MVIC, the functional walking shoes value was 36.85%MVIC, and the high-heel shoes value was 41.87%MVIC. Here, there was a differences among the shoe types ($p<0.05$). While there was not much difference between flat shoes and functional walking shoes, the value for high-heel shoes was significantly higher (Table 1).

DISCUSSION

Shoes are designed to absorb impact to protect the joints of the body, the foot and to prevent injury[14]. However, because many women are concerned about aesthetics and fashion, they are inclined to wear high-heel shoes without ample information on their effects[2, 3]. As a result, there have been reports that high heels cause spinal curvature, lower

back pain, ankle sprains, increased foot pain, overloading of the toes, shortening of the Achilles tendon, change of gait pattern and speed, increase of oxygen consumption, degenerative osteoarthritis and other negative symptoms including malign direct impacts on the lumbar vertebrae[9]. Choe et al. reported in their research that 5 cm and 7 cm high-heel shoes increased the muscle activation of the muscles surrounding the lumbar spine[15]. An also reported in his study that 7 cm high-heel shoes are one of the factors contributing to a build-up of pain, as well as deformity and injury in the lower extremity[16]. Our present research indicates that walking in high-heel shoes augments the muscle activation of the cervical, thoracic, and lumbar spine regions. However, the muscle activation of the L3 paraspinal muscle of the lumbar spine region was not affected by shoe type, be it flat, functional or high-heel. Thus, the L3 paraspinal muscle is activated regardless of the type of shoe worn during walking. This is not the case for the lumbar multifidus muscle, the activation of which was raised considerably while walking in high-heel shoes as opposed to flat or functional walking shoes. High-heel shoes increased the muscle activation of the lumbar multifidus muscle compensating for increased lumbar lordosis. It can thus be said that walking in high heels causes lumbar lordosis. Regarding the thoracic spine region, the muscle activation of the T12 paraspinal muscle was higher while walking in high-heel shoes than in flat shoes or functional walking shoes. Thus, the T12 paraspinal muscle was also affected by walking in high-heel shoes. In contrast, the muscle activation of the C4 paraspinal muscle in the cervical spine region was increased more while walking in functional shoes and high-heel shoes than in flat shoes, confirming that the C4 paraspinal muscle is influenced not only by high-heel shoes but also by functional walking shoes. In addition, the muscle activation of the upper trapezius was affected more by high-heel shoes than by functional walking shoes and, in turn, more by functional walking shoes than by flat shoes. Our results are similar to those of Song[17], who reported that discomfort is highest when wearing "killer heel" shoes, lower when wearing high-heel shoes and least when wearing sneakers. This implies that, the higher the heel, the greater the muscle activation around the paravertabral muscles. Even though shoes with heels are designed for walking, they presumably cause muscle fatigue by raising the muscle activation of the cervical spine muscles.

Thus, we recommend the wearing of flat shoes for walking to decrease the possibility of spinal deformity and injury, since even functional walking shoes were shown to potentially cause cervical muscle tension. Consequently, we recommend that subjects with spine problems should not wear high-heel shoes, and those who have cervical troubles should wear only flat shoes.

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