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CHANGES IN FOOT CHARACTERISTICS AFTER A 3-HOUR EXERCISE BOUT

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The purpose of this study was to determine if the foot swells significantly after a 3-hour bout of treadmill walking. Thirteen apparently healthy women walked on a treadmill at 1.43m/s for three hours. Before and after exercise each subject had shoe size determined, foot/ankle volume displacement taken, as well as foot molds made. The foot molds were measured for width of the big toe, ball of the foot, arch, and heel; as well as length of the arch and total foot. Dependent t-tests ($\alpha < .05$) were used to compare pre and post test results. Mean foot length increased by nearly a half size. Significant increases in the width of the ball of the foot (0.3 cm) and the width of the arch (0.4 cm) were noted. Volume displacement significantly increased .05 L with exercise. The foot increased in length and width, as well as volume displacement with a 3-hour bout of treadmill walking.

KEY WORDS: foot growth, treadmill walking.

INTRODUCTION: Studies have shown that higher levels of physical activity decreased mortality rates in otherwise equal people (Byberg et al., 2009; Leitzman et al., 2007). This has prompted society to take a greater initiative toward daily exercise to improve long-term health. For many, the exercise of choice is walking or running. This has led to an increase in activities such as jogging, hiking and fundraising walks such as the Breast Cancer or Relay for Life Walks. However, these types of activities have been noted to cause tenderness, pain and an aching fatigue in the feet.
Unfortunately, there is a lack of literature suggesting through what mechanisms these pains are caused. In runners, one study concluded that foot loading characteristics were altered post marathon (Nagel, Fernholz, Kibele & Rosenbaum, 2008). This change was seen as a mechanism for metatarsal fracturing due to inappropriate weight bearing in these areas. It could be hypothesized that the constant and repetitive shear and impact forces result in swelling and may alter characteristics of the foot. This study was aimed at understanding what occurs, characteristically, to the foot while in the shoe during long sessions of exercise. The purpose of this study was to determine if the foot swells significantly after a 3-hour bout of treadmill walking.

METHODS: Thirteen apparently healthy women (48$\pm$9 yrs) with a mean body mass of 73.4$\pm$12.7 kg and a mean height of 1.70$\pm$.05 m signed written consent forms approved by the University of Puget Sound internal review board before participating in the study.
The subjects' feet were measured using a Brannock Device, wax foot casting and water displacement before exercise. The foot casting was completed in warm wax. Wax was melted and poured into two plastic containers, one for each foot. Once cooled, subjects stepped into the wax and stood for 20 seconds. The molds were immediately placed in the refrigerator so the form would hold the shape of the foot. Foot and ankle volume were used to indicate overall swelling of the feet and ankles. A wash tub was filled with water to a line just above the ankle, the subject then stepped into the tub with both feet and a new line was marked. The volume of water displaced was measured and recorded by adding back in the water needed to match the line marked when the feet were in the tub.
The subjects were then asked to walk on the treadmill at 1.43m/s for three hours. Subjects were asked to consume 1.0 L of water during exercise. One bathroom break was typically taken half way through the exercise bout. At the end of exercise the subjects had their feet measured once again using the Brannock Device, foot molds and water displacement. Water displacement was the last measure to be completed to ensure that swelling was not reduced by the cold water.

The foot molds, both pre and post exercise, were measured for width of the big toe, ball of the foot, arch, and heel; as well as length of the arch and total foot length (See Figure 1). Dependent t-tests (α = 0.05) were used to compare pre and post test results for volume, as well as, foot size, foot length, big toe width, heel width, arch width, arch length, and ball of the foot width for both feet.

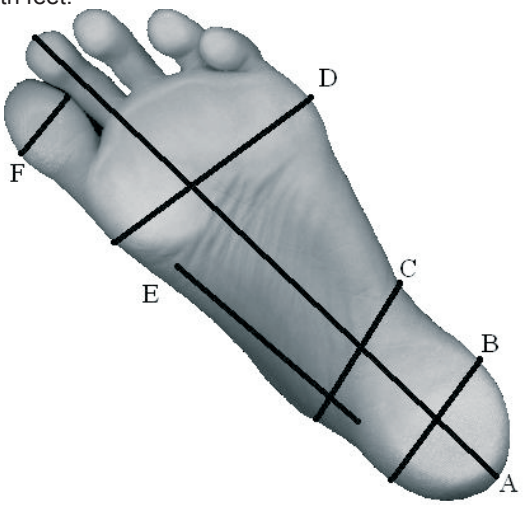

Figure 1: Foot mold measurements taken pre and post exercise: A – Total length: The total length from heel to toe end; B – Heel width: The maximum width of the heel; C – Instep width: The minimum width of the instep; D – Ball width: The maximum width measured from the first metatarsal joint to the fifth metatarsal joint; E – Length of the arch; F – Hallux width: The maximum width of the big toe.

RESULTS: All foot measurements can be found in Table 1. Big toe width did not increase significantly from pre to post testing in either foot. Mean foot length increased by nearly a half size in the right foot, while the molds indicated foot length significantly increased by 0.3 cm. Significant increases in the width of the ball of the foot (0.3 cm) and the width of the arch (0.3 cm) were noted. Volume displacement significantly increased .05 L from pre to post testing. Although the right heel did not significantly increase (p=.150), the left heel did significantly increase (p=.000) from pre to post testing. Foot size, foot length, arch width, and arch length all increased significantly in both feet with the three hour bout of treadmill walking.

Table 1
Foot Measurements Pre and Post Exercise

Measurement	Pre-test	Post-test	p
Foot Size Left	8.65 (±1.67)	8.77 (±1.76)	.000
Foot Size Right	8.65 (±1.77)	8.92 (±1.83)	.000
Foot Length Left in cm	23.53 (±1.23)	23.73 (±1.07)	.000
Foot Length Right in cm	23.67 (1.69)	24.08 (1.34)	.000
Big Toe Width Left in cm	2.60 (±.30)	2.84 (±.22)	.520
Big Toe Width Right in cm	2.79 (±.30)	2.86 (±.45)	.687
Ball of Foot Width Left in cm	9.13 (±.46)	9.44 (±.52)	.006
Ball of Foot Width Right in cm	9.15 (±.43)	9.51 (±.72)	.027
Heel Width Left in cm	5.60 (±.45)	5.93 (±.65)	.000
Heel Width Right in cm	5.59 (±.36)	5.65 (±.60)	.150
Arch Width Left in cm	3.14 (±1.19)	3.40 (±.75)	.008
Arch Width Right in cm	2.75 (±1.22)	3.22 (±.94)	.001
Arch Length Left in cm	10.16 (±1.28)	10.33 (±.85)	.000
Arch Length Right in cm	10.16 (±1.13)	10.44 (±1.21)	.029
Volume in L	1.75 (±.23)	1.80 (±.22)	.000

DISCUSSION: Although the fit of the foot bed is essential in shoe comfort, the exact dimensions for maximum long term wear have not been established (Witana, Goonetilleke, Au, Xiong, & Lu, 2009). Discomfort has been noted by many distance runners and walkers over the years and fit of the footwear has often been thought to influence foot health. In arthritis patients orthopaedic shoes are often prescribed, but a recent study found that running shoes were found to be just as comfortable (Hennessy, Burns & Penkala, 2007). Although shear forces within the shoe are one explanation for this discomfort, the swelling of the feet might be another explanation. The current study aimed to document the amount of swelling in the feet during an extended bout of exercise. Many walking events, such as the Breast Cancer Walk or Relay for Life ask participants to walk long bouts over many days. It may be beneficial to know how the foot is swelling to ensure comfort for a longer period of time during and after these walks. This study found that the foot size does change even with a relatively short walk. Since many walkers will walk more than the three hours the subjects were asked to walk in this study, it may be beneficial for participants to consider buying a shoe that is a half size larger than the shoe they normally wear. This solution is only part of the issue of foot growth though, as length of the shoe was just one area where foot growth was noted.

More problematic in fitting a shoe were the changes noted in the width of the ball of the foot and heel, as well as the changes in the arch length and width. It seems the repeated pounding in the walk caused the arch to flatten and lengthen, or for the arch to "fall". Witana, Feng, & Goonetilleke (2007) found that there were no significant differences in the fit of the mid foot in four different shoes they tested on 20 participants. The heel and forefoot ratings on fit seemed to be much more important. The results of the current study suggest that comfort in the midfoot might better be evaluated for running or walking shoes after an extended period in the shoe. Janisse (1992) goes so far as to suggest that shoe size is dependent on arch length, rather than total length of the foot. The subjects in this study were asked to wear a pair of shoes they normally would wear when completing a long walk. The age of shoe and the relative wear may have played a role in the amount of foot swell, particularly noted in the fallen arch measurements. In future studies, it might be beneficial to walk the subjects in new shoes to avoid this confounding factor.

The amount of swelling in the feet was significant in all areas measured, except the big toe. It may be that the big toe did not swell significantly in walking or in walking on a treadmill. When walking on a treadmill less toeing off is generally noted, as the speed of the belt drives the foot into the next stride reducing joint range of motion (Watt et al., 2010). It would be interesting to note if the swelling of the big toe might be noted in over ground walking.

CONCLUSION: The foot did swell significantly with a 3-hour bout of exercise. Increased width in the forefoot and rearfoot were noted, as well as changes in the arch dimensions and an increase in total length of the foot.

REFERENCES:

Byberg, L., Melhus, H., Gedeborg, R., Sundstrom, J., Ahlbom, A., Zethelius, B., Berglund, L.G., Wolk, A., Michaelsson, K. (2009). Total mortality after changes in leisure time physical activity in 50 years old men: 35 year follow-up population based cohort. *British Medical Journal,* 338:b688.

Hennessy, K., Burns, J., Penkala, S. (2007). Reducing plantar pressure in rheumatoid arthritis: A comparison of running versus off-the-shelf orthopaedic footwear. *Clinical Biomechanics,* 22(8), 917-924.

Janisse, D.J. (1992). The art and science of fitting shoes. *Foot and Ankle International,* 13(5), 247-252.

Leitzmann, M.F., Park, Y., Blair, A., Ballard-Barbash, R., Mouw, T., Hollenbeck, A.R., Schatzkin, A. (2007). Physical activity recommendations and decreased risk of mortality. *Archives of Internal Medicine,* 167(22), 2453-2460.

Nagel, A., Fernholz, F., Kibele, C., Rosenbaum, D. (2008). Long distance running increases plantar pressures benath the metatarsal heads: A barefoot walking investigation of 200 marathon runners. *Gait & Posture,* 27(1), 152-156.

Watt, J.R., Franz, J.R., Jackson, K., Dicharry, J., Riley, P.O., Kerrigan, D.C. (2010). A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. *Clinical Biomechanics,* 25(5), 444-451.

Witana, C.P., Feng, J., Goonetilleke, R.S. (2007). Dimensional differences for evaluating the quality of footwear fit. *Ergonomics,* 47(12), 1301-1317.

Witana, C.P., Goonetilleke, R.S., Au, E.Y.L., Xiong, S., Lu, X. (2009). Footbed shapes for enhanced footwear comfort. *Erogonomics,* 52(5), 617-628.

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