Applied Ergonomics 65 (2017) 163–167

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Gait characteristics in women's safety shoes

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ARTICLE INFO

Article history:
Received 29 December 2016
Received in revised form
26 April 2017
Accepted 16 June 2017

Keywords:
Gait
Personal protective equipment
Electromyography

ABSTRACT

Although workers in Japan are required to wear safety footwear, there is concern about occupational accidents that occur when wearing safety shoes. This study aimed to analyze the effect of wearing hardsoled safety shoes on both spatiotemporal gait characteristics and the muscle activity in the lower extremities.

Seventeen young women participated in this study. A 5-m gait trial and a surface electromyography trial were conducted while the women walked in either safety shoes or sports shoes. Paired t-tests were performed to analyze the differences in gait characteristics when walking in the two different pairs of shoes. Walking in safety shoes was associated with a significant increase in vastus lateralis, biceps femoris and tibialis anterior activity. This increased muscle activity in the lower extremities is likely compensating for the lower flexibility of the safety shoes.

1. Introduction

Safety footwear is designed to protect feet against a wide variety of injuries, such as impact, compression and puncture, and is used in various fields, including the manufacturing industry, construction/civil engineering industry and firefighting. Workers in these types of fields in Japan are required by law (Government of Japan, 1972) to wear safety footwear as personal protective equipment. Because there are more than 25,000 industrial falls per year in Japan (Government of Japan, 2016a), a fall prevention policy (Government of Japan, 2016b) was implemented. Safety footwear was cited in this policy as one cause of industrial falls. In light of this, attention has been paid to the association between shoes and falls in Japan. In the manufacturing industry, women in Japan are more often engaged in office work than in work requiring the use of safety footwear (Government of Japan, 2012). Consequently, there is a lack of data on women in Japan wearing safety footwear.

A previous study (Dobson et al., 2017) on safety footwear examined four factors (shaft height, shaft stiffness, boot mass, sole flexibility). Although boot mass increased the muscle activity of the lower extremity, the mass of the safety footwear used in the previous studies (Dobson et al., 2015; Lin et al., 2007; Kim et al., 2015; Schulze et al., 2011; Chiou et al., 2012) was 1 kg or more. Previous studies (Nurse et al., 2005; Lin et al., 2007; Dobson et al., 2015; Chiou et al., 2012; Nigg et al., 2003) indicated that soft-sole flexibility reduced the muscle activity of the lower extremity and that the muscle activity of the lower extremity increased the longer hard-sole safety footwear was worn. However, these studies focused on the hardness of the sole material, and only one study (Ito et al., 2014) quantified the flexibility of the forefoot segment of the shoes.

Shoe mass and sole flexibility affect not only shoe-related injuries but also the worker's comfort. Several studies on safety footwear have indicated a relationship between wearing safety footwear and occupational injuries, such as low back pain and hallux valgus (Akagi et al., 1995; Kido, 1989; Yahagi and Nemoto, 2003). Additionally, these studies suggested that foot pain and foot tiredness were related to the design of safety footwear, including the toe shape, weight, and flexibility of the front portion. Because wearing safety footwear can affect a worker's gait, it was hypothesized that injuries, foot pain or foot fatigue may be reflected in muscle activity in the lower extremity.

Furthermore, it was suggested that there was a gender difference in the effects of wearing safety footwear. Cross-sectional studies involving workers found that women had more foot problems than men (Marr and Quine, 1993; Werner et al., 2010), and that these problems could be exacerbated by wearing safety footwear (Jackson et al., 1980; Kido et al., 1991).

Several studies on general shoes, including oxford shoes and sports shoes, indicated that the sole hardness of footwear affected

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http://dx.doi.org/10.1016/j.apergo.2017.06.012

Abbreviations

VL	vastus lateralis
BF	biceps femoris
TA	tibialis anterior
LG	lateral head of the gastrocnemius muscle
EMG	electromyogram

gait characteristics (e.g., cadence, gait velocity, and step length) (Perry et al., 2007; Morio et al., 2009; Tsai and Powers, 2009). Additionally, hard-soled shoes are reportedly less comfortable than soft-soled shoes (Lane et al., 2014). In light of these earlier studies, the sole hardness of safety shoes likely affects not only the gait characteristics but also muscle activity, especially for women. Recently, materials for hard-resin toe caps and soles have been developed to reduce the mass and improve the balance of Japanese safety shoes. Thus, the study of muscle activity while wearing the safety shoes worn most often by workers may help shoe manufacturers design better shoes.

In this study, we focused on shoe mass and sole flexibility. The present study aimed to investigate the effect of walking in safety shoes on spatiotemporal gait characteristics and muscle activity.

2. Material and methods

2.1. Subjects

Seventeen female college students (mean (standard deviation); age 19.3 (0.9) years, weight 50.2 (5.0) kg, height 157.7 (4.3) cm, body mass index 20.2 (1.8) kg/m^2, foot length 230.1 (9.7) mm) participated in the study. None of the subjects had any orthopedic disease or lower limb injuries that affected their gait. Subjects were excluded from the analysis if the appropriate safety shoe size was unavailable or if the electromyography data could not be analyzed because of excessive noise.

The study protocol was approved by the institutional review board at Niigata University of Health and Welfare (No. 17,680–160,606). All subjects provided written informed consent before participating in the study.

2.2. Shoes

Two pairs of shoes commercially available in Japan were provided for each subject (Fig. 1). One pair of shoes was safety footwear commonly produced for women (670 g; longitudinal stiffness 35.8 N; MIDORI ANZEN Co., Ltd., Tokyo, Japan). These leather safety shoes have a hard sole and hard-resin toe cap, and conform to the Japanese Industrial Standards (JIS T8101, 2006). The other was a pair of general sports shoes made of fabric (470 g; longitudinal stiffness 14.7 N; Bridgestone Corporation, Tokyo, Japan). These sports shoes have a soft sole and no toe cap. Subjects used their own socks, and fastened the shoelaces or Velcro straps of the shoes at a comfortable tightness.

We adopted a method using a spring scale as a shoe longitudinal stiffness test (Fig. 2) (Abe et al., 2009). The sole flexibility was determined according to the method used by the National Institute of Occupational Safety and Health, Japan (National Institute of Occupational Safety and Health, 2006).

2.3. Procedure

Two experiments were performed on the same day for each subject in this study: a gait termination trial and a surface electromyography trial. The gait trial was performed first, followed by the electromyography trial. Shoe type was randomized, and each experiment was repeated for a total of six datasets (two shoes types × three trials). To minimize individual differences in tightness of the shoelaces or Velcro straps, one experimenter made final adjustments to the shoelaces and Velcro straps before each of the trials.

2.3.1. Gait termination trial

A walkway system (Walkway 7.60; Nitta Corporation, Osaka, Japan), measuring 5.02 m long and 0.53 m wide, was placed on a flat floor. The straight walkway sensor was approximately 2.68 m long and 0.53 m wide. The extensions where the subjects initiated

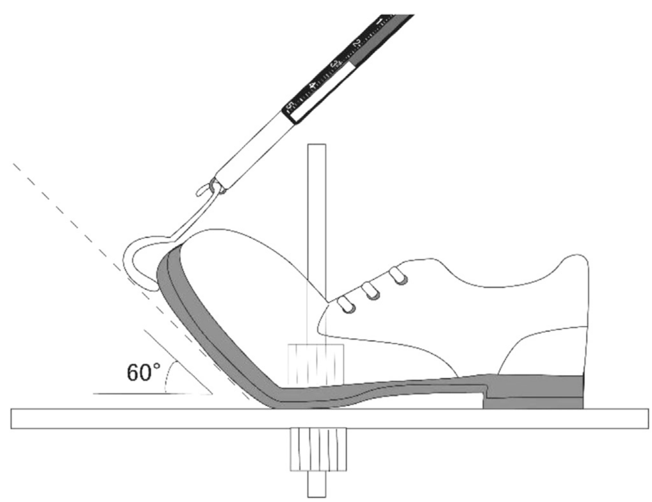

Fig. 2. Illustration of the shoe longitudinal stiffness test using a spring scale.

Fig. 1. Examples of the two different shoes worn by study participants. (Left): safety shoe; leather, foamed polyurethane double sole, hard-resin toe-cap, shoelace (Right): sports shoe; fabric, rubber sole, no toe-cap, Velcro strap.