EFFECTS OF AN INSOLE PROGRAM ON LOWER LEG EMG MUSCLE ACTIVITY IN THE MANUFACTURING SETTING

Carley, P., American International College, Springfield, MA; Swanson, E., American International College, Springfield, MA; Calvanese, C., American International College, Springfield, MA; Kessler, J., Hasbro Games, East Longmeadow, MA

Abstract

The manufacturing employees at HASBRO Games in East Longmeadow, Massachusetts agreed that the company's two-year old shoe insole program supplied by MEGAComfort Insoles was helping reduce the daily aches and pains while working on the factory concrete floors. However, the actual physical mechanism affecting these reported reductions in aches and pains remained unknown. A study was designed to use electromyography (EMG) to investigate lower leg muscle responses with and without insoles while performing similar work related tasks on the manufacturing concrete floors.

All participants reported spending approximately 60 to 90 percent of their workday standing or walking on concrete floors. The 43 randomly selected employees participating in the EMG study at HASBRO Games demonstrated a reduction in muscle activity for both the Tibialis Anterior and Gastrocnemius muscles groups with the EMG data revealing an overall reduction in lower extremity muscle activity by 9.6 percent. More specifically, there was a statistically significant 13.7 percent reduction for peak Tibialis Anterior to 8.8 percent for Gastrocnemius using only the insoles from the HASBRO's insole program. However, even though there was a reduction in average Tibialis Anterior muscle activity, the level was not statistically significant. The cumulative affect of reducing lower leg muscle activity complied daily, weekly, and annually can have an obvious beneficial benefit to employees exposed to prolonged standing postures. Implications from the study suggest that other manufacturing, hospitality, and service

industry settings consider the initiation of an insole program for those employees required to stand for at least 60 percent of their workday.

Introduction

Employees who work in static standing positions or associated work postures often complain of foot, knee, hip, and low back pain (Orlando & King, 2004). The reported pain response can increase as the employee ages or as the work demands increase (Tanaka, Takeda, Izumi, Ino, & Ifukube, 1999). Static postures often generate isometric muscle contractions which can cause a reduction in returning blood flow affecting surrounding tissues and can result in swelling in the lower extremities. Sanders (2004) reported Kroemer & Grandjean's research finding that reduced blood flow of the involved tissue can decrease oxygen exchange and the removal of cellular by-products leading to muscle fatigue and pain with the blood flow is constricted in proportion to the exertion and duration of forces.

One strategy engaged by companies is to establish an operational size specific polyurethane insole program to decrease the pain and discomfort levels of employees associated with static standing or static work postures. Fang et al. (2006) found that an appropriately designed shoe insole can reduce pain, stiffness, and functional limitation. Barnes and Smith (1994) found that shoe insoles provide both an increased area of support for the foot and reduced impact loads transmitted through the foot leg mechanism. Due to the increased support and reduced impact of ground reaction forces at the foot and lower extremity, there was an anticipated benefit in balance reactions, postural adjustments, and less muscle activity. Sanders (2004) indicated that a reduction in postural muscle contraction forces during static standing or during a static work posture could lead to a reduction of compression forces on blood vessels and nerve tissue. A reduction in compressive isometric muscle contraction forces can lead to improved circulation, enhanced removal of metabolic waste materials, a reduction in fatigue, and reduced postural discomfort over prolonged time periods.

The study at Hasbro Games investigated the actual peak and average EMG lower leg muscle activity of 43 manufacturing employees whose primary tasks involved static and dynamic standing postures for 60 to 90 percent of their workday. The insoles used for the study were company issued polyurethane insoles available in whole sizes that would partially mold to the employee's unique foot pressure profile. The purpose of the study was to investigate the physiological effects of those polyurethane shoe insoles on lower extremity muscle contractions during static and dynamic standing using electromyography (EMG) to monitor levels of muscle activity in the right Tibialis Anterior and Medial Gastrocnemius. Based on the current literature, the study's null hypothesis was that no difference in the means for peak and average EMG activity would be demonstrated between insole and no insole trials for both leg muscle groups. The alternative hypothesis was that the use of a company's insole program would result in lower means for peak and average EMG activity for the same leg muscle groups between both trials.

Methods

The study employed the use of a BioPac MP-30 EMG device to record and monitor each subject's right Tibialis Anterior and Medial Gastrocnemius muscle for peak and average EMG activity relative to the participant's own maximum voluntary contraction (MVC). The subjects' MVC for both muscle groups were recorded without wearing insoles and with standard instructions to stand on the very tips of their toes for 15 seconds and then to maintain balance only on their heels for 15 seconds as hard as they could possibly endure. Participants were instructed to read and discuss the purpose of the study and upon conclusion sign the informed consent form approved by the human subjects committee. The data entry researcher was blinded as to the participant's trial for wearing or not wearing the insoles until both trials were complete.

The surface electrodes were applied as instructed by the BioPac manufacturer with the skin being prepared with a rigorous application of water soaked paper towels to the intended electrode placement sites for effective abrasion of the skin surface. The skin was appropriately dried and the manufacturer's electrodes applied with the ground located over the medial aspect of the tibia for both the Tibialis Anterior and Gastrocnemius muscle sites. The remaining electrodes were securely applied to the appropriate muscle locations and the entire right calf electrodes were secure with an ACE wrap to maintain the electrode placement and reduce the potential for artifact during data collection.

Once the MVC requirements and secured electrode placements were satisfied, the participant was asked to maintain a period of relaxed static standing for 30 seconds before beginning a standardized task that assimilated the physical activities of the workplace on the factory concrete floor. The volunteering participants were chosen randomly during their regular shift and tested with a new pair of the standard insoles from the company's established program. The activity involved a performance of reaching and lifting a 6-ounce weight, then carrying the object 10 feet and placing the 6-ounce weight on a waist high counter. The participant again reached for the object and kept repeating the process continuously for a period of one minute on the factory floor. The activity was repeated again with the same distance and weighted object for the same length of time that included the same return to static standing for a set 30-second period before simulating the same worker activities.

The settings for the BioPac MP-30 EMG data acquisition and analysis device were pre-established in the input channel parameters. The digital filters were set with one high pass filter at 30.00 Hz and a Q setting of 0.70700. The hardware was set at a gain of 2500, offset at 0.0 mV, input coupling for alternating current with 1kHz LP and the unit parameters were set for EMG 30-500 Hz for both channels involving the medial head of the Gastrocnemius and Tibialis

Anterior. EMG signal data were collected in raw EMG form and integrated form with a rectified average over 50 samples per second. Data were analyzed using the BioPac Lab Pro 3.6.7 version software for data analysis from the above-described EMG signals for both muscles for all the participants in the same manner.

Results

Analysis of the EMG results revealed a decrease in peak and mean Tibialis Anterior muscle activity with the use of insoles. While both Tibialis Anterior EMG activities with the use shoe insoles indicated lower muscle activity, only the peak EMG demonstrated a statistically significant (0.05 level) reduction in Tibialis Anterior activity. There was also a decrease in both peak and mean EMG Gastrocnemius activities with participants wearing the company insoles when compared with no insoles. However, in this case, both peak and mean Gastrocnemius EMG muscle activity were reduced at a statistically significant (0.05 level) for those trials using of insoles. The participants' subjective responses surveyed for a qualitative assessment, revealed 98 percent of the participants stated a reduction in discomfort levels at the feet, lower legs, hips, and low back while wearing the insoles since the start of the HASBRO insole program.

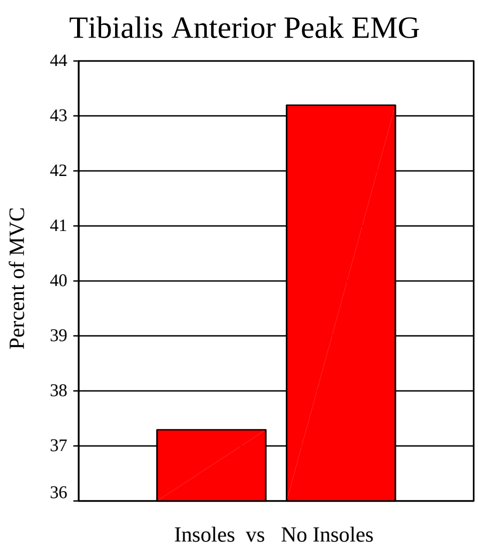

Fig. 1 Peak EMG Tibialis Anterior

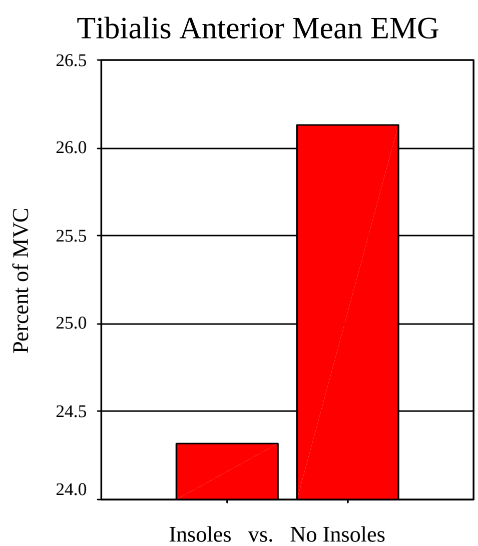

Fig. 2 Mean EMG Tibialis Anterior

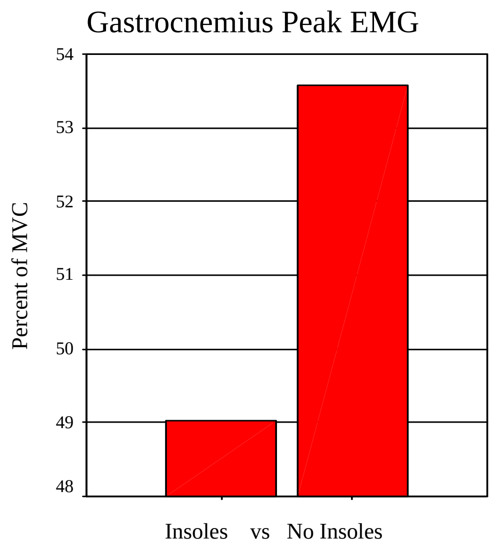

Fig. 3 Peak EMG Gastrocnemius

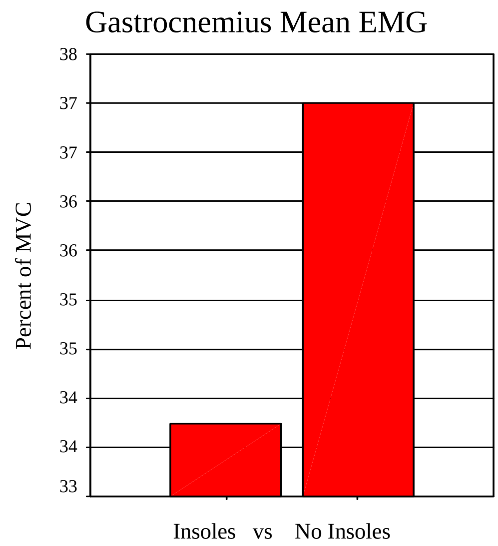

Fig. 4 Mean EMG Gastrocnemius

Paired Samples Test – Paired Differences					
Insoles vs. No Insoles Trial	Mean EMG Difference	Std. Dev.	95% Confidence Interval of the Difference		t
1. Peak EMG Tibialis Anterior	-5.9037	5.41	-7.571	-4.237	-7.147*
2. Average EMG Tibialis Anterior	-1.8142	2.37	-2.546	-1.082	-5.004
3. Peak EMG Medial Gastroc	-4.5326	5.73	-6.299	-2.766	-5.179*
4. Average EMG Medial Gastroc	-3.2605	3.27	-4.269	-2.251	-6.521*

Table 1. Results of the Paired T test of the insoles trial compared to no insoles trial for both leg muscle groups, Peak and Mean EMG activity (*Significant at 0.05 level).

Discussion

Hypothesis testing of the EMG data

The null hypothesis stated that there would be no difference in the means for either peak or average EMG activity for both the Tibialis Anterior and Medial Gastrocnemius for those using insoles compared to those conditions without insoles. Based on the literature, an alternative hypothesis was proposed stating there would be less peak and mean EMG activity for both leg muscle groups for those wearing insoles supplied through the company's insole program. A paired one-tailed Student T test in comparing the means revealed that in three out of the four trials, there was sufficient evidence to support the claim that the EMG means for those wearing insoles were significantly less than those not wearing insoles with the exception for the mean EMG of the Tibialis Anterior (EMG trial 1 $p = 4.48$, EMG trial 2 $p = 5.26$, EMG trial 3 $p = 2.97$, EMG trial 4 $p= 3.54$).

Static Biomechanical Effects

As many of us can attest, painful, tired feet can have a disruptive effect on a demanding workday. The long-term effects can accelerate joint pain and low back claims with negative influences on productivity. For those in the hospitality industry, it may also affect the customer interaction impacting the entire organization. Employees required to stand on concrete surfaces are anxious for a pain-reducing solution that is also cost effective. The balance of cost and true benefit to the employee must be based on objectively recorded physiologic differences rather than the latest marketing efforts implying positive benefits. The results of the HASBRO EMG study provided encouraging support for properly designed insoles that can increase the foot surface contact, provide strategic cushioning, and reduce the need for excessive compensatory lower leg muscle activity.

Fernberg (1999) noted Ford's observation that the act of static standing alone is not the concern but the small area [surface of the foot] in which the pressure of body weight is applied over a standard work shift. Workers, like all us, will compensate for uncomfortable foot pressure by lifting up one leg on a higher surface or momentary shifts in body weight from one side to the other. Meijsen and Knibbe (2007) examined operating nurses standing for prolonged periods of time that resulted in additional positional compensation, swelling in the legs, and possible joint complications beyond muscle fatigue factors noting that prolonged standing should be considered as an occupational risk factor.

Fernberg (1999) implied the affect of different floor surfaces that people work on will be magnified by the age and types of footwear worn. Prior studies on balance reactions, floor interfaces, and footwear choices have shown that excessive balance adjustments are observed with workers wearing older footwear, worn sneakers, and standing on soft rubber floor matting material (Carley, 1999). In those studies, insoles shaped to accommodate the normal profile of their feet not only increased the foot surface contact but unexpectedly improved standing balance reactions, lower maximal exertions, and directional control. Those workers tested with workboots and contoured polyurethane insoles demonstrated the most efficient balance reaction profile in all age groups from 20 to 59 years old.

Studies at American Saw Company (Lenox Saw Blades) and HASBRO Games examined the subjective responses of employees wearing polyurethane insoles compatible with the weight bearing surface of the foot reported reductions in complaints of foot and back pain with the greatest reductions occurring when the insoles were worn with workboots (Carley & Swanson, 2001). Orlando and King (2004) investigated the perceptions of standing discomfort that statistically described no “significant differences were found between flooring condition and subjective ratings of fatigue or discomfort in various body regions” (p. 63).

Dynamic Biomechanical Effects of Insole Design

Most over-the-counter insoles placed in work footwear are designed to add cushioning material without attempting surface contours to maximize the potential biomechanical benefits. The more expensive over-the-counter polyurethane insoles will usually incorporate some type of heel cup and quasi-arch cushion design. However, due to the limited retail space available, each packaged insole will fit 3 to 4 shoe sizes with lines showing the consumer where to cut the excess insole material. Reducing the insole 3 to 4 shoe sizes causes the proportions of their respective heel cup and arch locations to become distorted against the foot's surface. The resulting location and size of these two components become misplaced when the consumer must trim the forefoot section to correct for three to four sizes. For example, a worker who performs the recommended trimming [size 8-12] to a size 8 foot, will now experience a much larger heel cup area and arch cushion much more forward under the foot's surface. The larger size heel cup and location of the arch material for a size 12 is now disproportionate for someone with size 8-foot surface after performing the recommended trimming of the over-the-counter insole.

The insoles worn in the EMG study were from HASBRO's insole program supplied from MEGAComfort that were available in whole sizes, no half sizes, and there was no trimming performed on any insole. As a result, the appropriate dimensions for heel cups and placement of arch cushioning were preserved and size specific with the requisite amount of polyurethane material based on the foot size and not based the available retail shelving space. The benefit of size specific insoles in suitable work footwear optimizes subtalar joint orientation during static and dynamic standing positions. The optimum ankle position with polyurethane cushioning permits necessary adjustments and cushioning influences that extended to the entire kinetic chain of the legs to the low back area based on early subjective studies (Carley & Swanson, 2001; Orlando & King, 2004). The subjective responses in these earlier studies confirmed comparable outcomes of less discomfort reported in the low back area with a reduction in internal rotation of the tibia and femur, less anterior tilting of the pelvis, a limited bias towards trunk flexion (Oatis, 2002; Razeghi & Batt, 2000).

Polyurethane Insole Impact during the Gait Cycle

The gait cycle consists of the stance phase and the swing phase (Barnes & Smith, 1994). The stance phase is comprised of three elements referred to as heel strike, single limb support, and push off. During the stance phase, body weight is transferred from the heel to the forefoot as the foot transitions from pronation to supination (Cheung & Ng, 2008). During heel strike, Dixon and Dixon (2007) suggested the function of properly designed insoles could enhance the cushioning and limit subtalar eversion thereby reducing the peak loading response by the Tibialis Anterior. Otherwise, excessive and repeated dynamic loading upon heel strike could create the likelihood of overuse injuries (Dixon & Dixon). Previous studies have shown that the inversion/eversion movement of the foot is transferred through ankle joint into external/internal rotation of the tibia (Nigg, Khan, Fisher & Stefanyshyn, 1997). Therefore, weight bearing internal/external rotation of the tibia relative to femur is a primary kinematic variable affecting postural biased positions leading to potential injuries to the foot, knee, hip, and low back areas.

During the single limb support and the contralateral swing limb advancement component, the weight-bearing foot rolls into a pronated position with both the forefoot and rear foot in contact with the ground as knee flexion gives way to hip and knee extension (Barnes & Smith, 1994). According to Cheung and Ng (2008), the foot inverter muscles are the major rear-foot stabilizing muscles that if become less efficient in controlling foot pronation will lead to higher plantar forces on the medial structures of the foot. Higher plantar force conditions can be related to overuse and fatigue of these stabilizing muscles. When the inverter muscles become fatigued, they become less efficient and the muscle tuning system becomes less responsive to external forces altering the movement patterns during standing balance and weight shifting (Nigg, 2001).

The beneficial use of modified polyurethane insoles has been observed in the gait cycle and for the treatment of medial compartment knee osteoarthritis (Fang, Taylor, Nouvong, Masih, Kao, and Perell, 2006). The insoles utilized in this study were designed with more material placed at the arch and surrounding the heel area with a top layer that would compress further improving the insole's conforming response to the foot profile. The added cushioning around the heel cup area could influence calcaneal motion upon heel strike thereby mitigating the opposing ground reaction force with less peak eccentric muscle activity from the Tibialis Anterior. The EMG study's data evidenced the statistically significant reduction of peak EMG recordings while wearing the insoles compared to no insoles. Overall, the reduction in muscle activity decreases the risk associated with standing fatigue thereby creating a biomechanically efficient advantage to the employee with the established company's insole program.

Proprioceptive and Sensory Feedback of Properly Designed Insoles

Previous researchers have agreed that the surface upon which an employee stands is a major contributing factor in the reported fatigue and their perception of discomfort related to prolonged standing (Carley & Swanson, 2001, Meijsen & Knibbe, 2007; Orlando & King, 2004: Hou & Shiao, 2006). Floor mats are commonly used to reportedly reduce fatigue but their location under the footwear's surface and not under the person's foot surface places the floor mat at a considerable disadvantage for sensory and proprioceptive feedback necessary for efficient muscle and balance adjustments. Standing on soft surfaces may be perceived as being comfortable initially; soft surfaces not under direct contact with the foot can decrease one's ability to balance and does little to absorb shock (Fernberg, 1999).

Nurse, Hulliger, Wakeling, Nigg, and Stefanyshyn, (2005) stated, "Sensory feedback from the feet may affect specific motor unit pools during different activities. Changing the texture, without changing the geometry, of the shoe insert can alter muscle activity during walking. This may be useful in the prescription of footwear interventions and suggest that footwear may have sensory as well as mechanical effects" (p. 496). Additional researchers have described the same importance for the proprioceptive feedback of the feet to adjust for balance and posture. Pope, Goh, and Magnusson (2002) stated, “In recent years, more attention has been given to the neural feedback system. Proprioception is an important factor in stabilization of the joints and throughout the spine. It is probable that proprioception deficits are associated with low back pain and low back injuries” (p. 51).

Polyurethane insole material assists in protecting the body from potentially harmful and repeated impact by dampening the accumulative affect of peak and average impact forces responded to by muscle control as well as attenuating frequencies of the opposing force (Barnes & Smith, 1994). Hansen, Winkel, and Jorgensen (1997), conducted an EMG study to determine the influence of using a floor mat compared to cushioned shoes during an extended static standing work day. The cushioned shoe provided a greater reduction in heel impact during static and dynamic positions with a reduction in postural muscle fatigue.

Conclusion

The study objectively investigated the affect of polyurethane insoles on workers that produced statistically significant reductions in lower leg muscle activity at the workplace. The reduction of the Tibialis Anterior and Medial Gastrocnemius muscle activity significantly decreases the potential for fatigue and potential for injury in the workplace. The cost effective intervention is applicable for both the static and dynamic standing setting where exposure to foot and back overuse may be a concern. It is the opinion of the researchers that a quality constructed work shoe or boot with a well designed polyurethane insole could realistically establish the a range of anti-fatigue footwear with the ability to conform to the worker’s particular and unique foot pressure profile. HASBRO Games choice for the current insole program has established statistically significant benefits for the employee as well as a proven cost benefit initiative for the employer.

The findings of this study provided further encouragement for HASBRO's two-year insole program by demonstrating a reduction in lower leg muscle activity can be objectively achieved with the use of appropriately designed insoles while standing and working in the manufacturing environment. The beneficial use of full contact polyurethane insoles represents a cost effective option with the while aiming to improve worker productivity with less fatigue at the end of the workday. The insole program has application to many sectors of the economy that would be acutely needed in a time of global competitiveness. Recommended future studies should include comparisons of the aging worker since the changing demographic factors may influence subjective responses and EMG muscle activity for foot and ankle control motion while performing work tasks on concrete floors in the manufacturing, hospitality, and service sector settings.

Appreciation

The researchers would like to thank Jack Pope, head of safety at Hasbro Games for his administrative support, Rosa DeRamos, Ph.D., for her statistical assistance, and Dr. Kevan Orvitz for his support of additional insoles for the Hasbro Insole Program.

References

Aaltonen, S., Karjalainen, H., Heinonen, A., Parkkari, J., & Kujala, U. M. (2008). Insoles, external joint supports, and multi-intervention training programs reduce sports injuries. *The Journal of Bone and Joint Surgery, 90-A*(2), 449.

Barnes, R. A., & Smith, P. D. (1994). The role of footwear in minimizing lower limb injury. *Journal of Sports Sciences, 12, 341 – 353.*

Carley, P. (1999). Healing the pain: Low-cost, size specific polyurethane shoe inserts help in managing perceived back and knee pain. *Occupational Health and Safety (68), 8, 92-94.*

Carley, P., & Swanson, E. (2002). *Are concrete floor surfaces really bad for workers or is there more to it than the floor itself?* Paper presented at the Annual Meeting of the American Physical Therapy Association, Cincinnati, Ohio, USA.

Cheung, R., & Ng, G. (2008). Influence of different footwear on force of landing during running. *Physical Therapy, 88*(5), 620-628.

Dixon, S. (2007). Influence of a commercially available orthotic device on rearfoot eversion and vertical ground reaction force when running in military footwear. *Military Medicine, 172*(4), 446-450.

Esterman, A., & Pilotto, L. (2005). Foot shape and its effect on functioning in royal australian air force recruits. Part 2: Pilot, randomized, controlled trial of orthotics in recruits with flat feet. *Military Medicine, 170*(7), 629-633.

Fang, M. A., Taylor, C. E., Nouvong, A., Masih, S., Kao, K. C., & Perell, K. L. (2006). Effects of footwear on medial compartment knee osteoarthritis. *Journal of Rehabilitation Research & Development, 43*(4), 427-434.

Fernberg, P. M. (1999). Don't stand for fatigue. *Occupational Hazards, 77*.

Hansen, L., Winkel, J., & Jorgensen, K. (1998). Significance of mat and shoe softness during prolonged work in upright position: Based on measurements of low back muscle emg, foot volume changes, discomfort and ground force reactions. *Applied Ergonomics, 29*(3), 217-224.

Hou, J., & Shiao, J. S. (2006). Risk factors for musculoskeletal discomfort in nurses. *Journal of Nursing Research, 14*(3), 228-236.

House, C. M., Dixon, S. J., & Allsopp, A. J. (2004). User trial and insulation tests to determine whether shock-absorbing insoles are suitable for use by military recruits during training. *Military Medicine, 169*(9), 741-746.

Marinakis, G., & Catalfamo, P. (2004). The effect of separated-arms foot orthoses on the lower body and trunk kinematics during level walking. *Journal of Prosthetics and Orthotics, 16*(3), 87-93.

Marr, S. J., & Quine, S. (1993). Shoe concerns and foot problems of wearers of safety footwear. *Occupational Medicine, 43*, 73-77.

Meijsen, P., & Knibbe, H. J. (2007). Prolonged standing in the or: A dutch research study. *Association of periOperative Registered Nurses, 86*(3), 399-414.

Nigg, B. M. (2001). The role of impact forces and foot pronation: A new paradigm. *Clinical Journal of Sports Medicine (11), 2-9.*

Nigg, B. M., Khan, A., Fisher, V., & Stefanyshyn, D. (1998). Effect of shoe insert construction on foot and leg movement. *Medicine & Science in Sports & Exercise, (30), 4, 550-555.*

Nigg, B. M., Khan, A., Fisher, V., & Stefanyshyn, D. (1997). Effect of shoe insert construction on foot and leg movement. *Medicine & Science in Sports & Exercise, 30*(4), 550-555.

Nurse, M. A., Hulliger, M., Wakeling, J. M., Nigg, B. M., & Stefanyshyn, D. (2005). Changing the texture of footwear can alter gait patterns. *Journal of Electromyography and Kinesiology, 15*, 496-506.

Oatis, C. (2003). *Kinesiology: The mechanics and pathomechanics of human movement.* (1st ed.). Baltimore, MD: Lippincott Williams & Wilkins.

Orlando, A. R., & King, P. M. (2004). Relationship of demographic variables on perception of fatigue and discomfort following prolonged standing under various flooring conditions. *Journal of Occupational Rehabilitation, 14*(1), 63-76.

Pope, M. H., Goh, K. L., & Magnusson, M. L. (2002). Spine ergonomics. *Annual Review of Biomedical Engineering, 4*, 49-68.

Razeghi, M., & Batt, M. E. (2000). Biomechanical analysis of the effect of orthotic shoe inserts: A review of the literature. *Sports Medicine, 29*(6), 425-438.

Sanders, M. J. (2004). *Ergonomics and the management of musculoskeletal disorders*. (2nd ed.). Elsevier Health Sciences: Butterworth - Heinemann.

Tanaka, T., Takeda, H., Isumi, T., Ino, S., & Ifukube, T. (1999). Effects on the location of the centre of gravity and the foot pressure contribution to standing balance associated with aging. *Ergonomics, 42*(7), 997-1010.

Tsung, B. Y., Zhang, M., Mak, A. F., & Wong, M. W. (2004). Effectiveness of insoles on plantar pressure redistribution. *Journal of Rehabilitation Research & Development, 41*(6A), 767-774.