
**Journal of Sports Sciences**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

# Changes in running mechanics using conventional shoelace versus elastic shoe cover

Youlian Hong[a]; Lin Wang[b]; Jing Xian Li[cd]; Ji He Zhou[a]
[a] Department of Sports Medicine, Chengdu Sports University, Chengdu, China [b] Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Hong Kong [c] School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada [d] Department of Health and Exercise Science, Tianjin Sports University, China

First published on: 22 December 2010

**To cite this Article** Hong, Youlian , Wang, Lin , Li, Jing Xian and Zhou, Ji He(2011) 'Changes in running mechanics using conventional shoelace versus elastic shoe cover', Journal of Sports Sciences, 29: 4, 373 — 379, First published on: 22 December 2010 (iFirst)

**To link to this Article: DOI:** 10.1080/02640414.2010.534805

**URL:** http://dx.doi.org/10.1080/02640414.2010.534805

*Journal of Sports Sciences*, February 15th 2011; 29(4): 373–379



# Changes in running mechanics using conventional shoelace versus elastic shoe cover

YOULIAN HONG[1], LIN WANG[2], JING XIAN LI[3,4], & JI HE ZHOU[1]

[1]*Department of Sports Medicine, Chengdu Sports University, Chengdu, China,* [2]*Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Hong Kong,* [3]*School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada, and* [4]*Department of Health and Exercise Science, Tianjin Sports University, China*

*(Accepted 21 October 2010)*



**Abstract**

The purpose of this study was to determine whether there are differences in the perceived comfort, plantar pressure, and rearfoot motion between laced running shoes and elastic-covered running shoes. Fifteen male amateur runners participated in the study. Each participant was assigned laced running shoes and elastic-covered running shoes for use during the study. The perceived comfort, plantar loading, and rearfoot motion control of each type of shoes during running were recorded. When the laced running shoes and elastic-covered running shoes were compared, the elastic-covered running shoes were given a lower perceived comfort rating in terms of shoe length, width, heel cup fitting, and forefoot cushioning. The elastic-covered running shoes also recorded higher peak plantar pressure in the lateral side of the forefoot, as well as larger maximum rearfoot pronation. Overall, shoelaces can help runners obtain better foot–shoe fit. They increase the perceived comfort, and decrease the maximum pronation and plantar pressure. Moreover, shoelaces may help prevent injury in running by allowing better control of the aforementioned factors.

**Keywords:** *Footwear, comfort, plantar pressure, rearfoot motion, elastic-covered running shoe*

## Introduction

Running is one of the most popular leisure sports activities (Fox & Rickards, 2004). Impact force has been evaluated to be approximately 2.5 times the runner's body weight in distance running (Cavanagh & Lafortune, 1980). High injury rates have been reported in runners. The recorded injury rate per 1000 h of training is 2.5 in long-distance/marathon runners and 5.6–5.8 in sprinters and middle-distance runners (Lysholm & Wiklander, 1987). A 12-month follow-up survey of 1680 runners found that 48% of them experienced at least one musculoskeletal injury (Walter, Hart, McIntosh, & Sutton, 1989).

Athletic footwear has been linked to the prevention of injuries and to increased comfort in running (McKenzie, Clement, & Taunton, 1985; Riddle, Pulisic, Pidcoe, & Johnson, 2003; Taunton et al., 2003), because it influences running biomechanics. Research in footwear biomechanics has demonstrated that differences in the design of running shoes, including heel height, insole materials, and height of the shoe cup, can influence rearfoot motion (Cheung & Ng, 2007; DeWit, DeClercq, & Lenoir, 1995; Hamill, Bates, & Holt, 1992; Kersting & Brüggemann, 2006), plantar pressure loading (Dixon, 2008; Henning & Milani, 1995; Verdejo & Mills, 2004), and shoe comfort (Cheung & Ng, 2007; Chiu & Wang, 2007; Hong, Lee, Chen, Pei, & Wu, 2005; Milani, Hennig, & Lafortune, 1997; Mündermann, Stefanyshyn, & Nigg, 2001), which have been widely used as indicators of running biomechanics.

Shoelaces have been considered an important part of running shoes and have drawn the attention of many scientists. Frey (2000) suggested that a shoelace provides a more comfortable shoe fit and can distribute stress evenly across the dorsum of the foot. However, no direct evidence exists to support this suggestion. In a study of soccer players who showed excessive pronation in running, a pair of soccer shoes with the pronated lacing technique was found to be better at controlling rearfoot motion than soccer shoes with other lacing conditions (Sandrey, Zebas, & Bast, 2001). Hagen and Henning (2008, 2009) studied plantar pressure distribution, shock attenuation, and rearfoot motion in running shoes with different lacing conditions. Their participants were made to wear the same shoes for a number of times,

Correspondence: J.-X. Li, School of Human Kinetics, University of Ottawa, 125 University Street, Ottawa, Ontario K1N 6N5, Canada. E-mail: jli@uottawa.ca

ISSN 0264-0414 print/ISSN 1466-447X online © 2011 Taylor & Francis
DOI: 10.1080/02640414.2010.534805

with different lacing patterns each time: eyelets 1–2; eyelets 1–6; eyelets 1–7; and eyelets 1, 3, and 5. In the six-eyelet lacing condition, the participants laced the shoes at different tightness according to their own perception of weak, regular, and tight conditions. It was found that shoe-lacing conditions have a significant influence on foot–shoe coupling in running. A tighter coupling due to stronger lacing results in the better use of the running shoes. Although literature on shoe lacing and running biomechanics is limited, existing published studies have shown that the shoelace has impacts on running biomechanics (Hagen & Henning, 2008, 2009; Hagen, Homme, Umlauf, & Henning, 2010). Recently, some shoe companies have designed a new type of running shoes with an elastic upper envelope, replacing the traditional lacing structure. However, the effects of the new design on running biomechanics in terms of comfort, cushioning, and rearfoot motion control during running have yet to be examined. Therefore, the aim of this study was to determine whether there are differences in the perceptions of comfort, cushioning, and rearfoot motion control between running shoes that utilize the shoelace system and those that do not. The null hypothesis of the study is that there is no difference in the perceived comfort, plantar pressure, and rearfoot movement between conventional laced shoes and elastic-covered shoes.

## Methods

### *Participants*

Fifteen male amateur runners (age 20.3 ± 1.6 years; mass 62.5 ± 5.1 kg; height 1.70 ± 0.04 m), who were all heel strikers and a shoe size 41 (European shoe size), were recruited to participate in the study. Inclusion criteria were that they should have no history of disease in the neuromuscular, vestibular or vision systems, and that they had not experienced any injury in the 6 months prior to the study. Only males were recruited for the study to prevent any possible gender differences in running capacity. The participants signed an informed consent. The study received approval from the local institutional review board.

### *Shoes*

The prototype running shoes were provided by a professional shoe manufacturer. The shoes differ only in terms of having shoelaces or an elastic shoe cover, as shown in Figure 1. Each participant was given two pairs of shoes, one with laces and the other with the elastic shoe cover.

This study used the mathematical model of shoe lacing that recommends the X-lacing pattern (con-

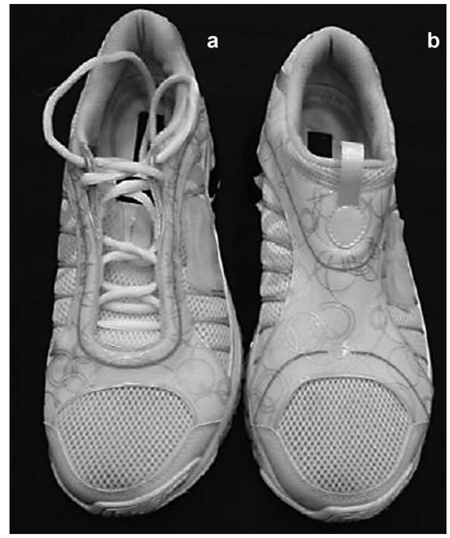


Figure 1. Shoes tested in this study: (a) laced running shoes and (b) elastic-covered running shoes.

ventional crisscross pattern) as the best and strongest way of lacing shoes (Polster, 2002). Each participant adjusted the shoelaces according to his preferred tightness.

### *Experimental protocol*

The study consisted of three tests, which were arranged to be on the same day for each participant. First, participants were asked to perform the perceived comfort test on an outdoor normal running track. Then they returned to the indoor laboratory to undertakee the plantar pressure test and then the rearfoot movement test. A 30 min rest was allowed between tests. In each test, test shoes were randomly assigned to the participant.

*Perceived comfort test.* A questionnaire with visual analogue scale, which has been used in previous studies and has been shown to be reliable (Cheung & Ng, 2007; Clinghan, Arnold, Drew, Cochrane, & Abboud, 2008; Mündermann et al., 2001), was used to analyse perceived comfort ratings of running shoes. The questionnaire had nine questions that addressed the following: Q1 (overall comfort), Q2 (heel cushioning), Q3 (forefoot cushioning), Q4 (medial–lateral control), Q5 (arch height), Q6 (heel cup fitting), Q7 (shoe heel width), Q8 (shoe forefoot width), and Q9 (shoe length). The perceived comfort test was conducted on a normal running track. The participants completed a trial involving a 450 m run at a comfortable speed on a synthetic rubber sports track. After the trial, each participant was instructed to answer one set of questions immediately. Another trial was conducted after a 15 min break using the alternate shoe type. Finally, two completed questionnaires were collected: one for laced running shoes and the other for elastic-covered running shoes. This study adopted a 150 mm scale, in which the right-hand end was labelled the "most comfortable imaginable", while the opposite end was labelled the "least comfortable imaginable".

*Rearfoot movement test.* The participants were asked to run on a treadmill at 3.8 m $\cdot$ s$^{-1}$. A video camera (9800, JVC Inc., Japan) with a sampling frequency of 200 Hz was positioned behind the treadmill to record the rearfoot movement of the runners. Four light reflective spherical markers were attached to the shoe on each participant's dominant leg. This approach has been described elsewhere (Cheung & Ng, 2007; Hamill, Moses, & Seay, 2009; Nigg & Morlock, 1987) and is one of the standard methods for comparing the rearfoot motion control properties of running shoes, as stipulated by the American Society for Testing and Materials (ASTM, 2006). The first marker was glued over the Achilles tendon, 4 cm above the ankle joint. The second marker was placed midway on a line defined by the bisection of the knee and the marker on the Achilles tendon. The third marker was placed on the centre the heel cap at the insertion of the Achilles tendon. The fourth marker was attached to the centre of the heel cap just above the shoe sole. The angle between the line linking the first and second markers, and the line linking the third and fourth markers, represents the rearfoot inversion or the eversion angle. To correct the differences in marker position between participants, the participants were asked to stand in a standard position. The standard position involves standing with the medial edges of the shoe heels 5 cm apart, with the feet abducted at 7$^\circ$ (ASTM, 2006). The rearfoot angle of each participant was then measured as the reference for determining the same angle measured during the running test. After the reference neutral position angle was determined, the participants ran for 3 min in each type of shoes, and the 10 foot strikes in the last 30 s were filmed. The video images were then processed using the Ariel Motion Analysis System (APAS, Ariel Dynamics Inc., USA) to determine rearfoot motion. A positive value against the reference position indicates inversion of the heel to the shank, which implies a supinated position. In contrast, a negative value indicates eversion, which implies pronation. The dominant leg was determined by kicking a ball. All participants in the study identified their right leg as their dominant leg.

*Plantar pressure test.* An in-shoe force sensor system (Novel Pedar System, Germany) was used to collect the plantar local loading data during running. Only the plantar pressure of the dominant leg was measured. The sampling frequency was set at 100 Hz. The participants were asked to run on a treadmill at 3.3 m $\cdot$ s$^{-1}$ for 2 min. Ten successful trials were subsequently used for data analysis.

### *Data reduction*

The Ariel Motion Analysis System software was used for digitizing and analysing the video images. To evaluate the rearfoot motion, four parameters were analysed: rearfoot touchdown angle (TDR), rearfoot maximal pronation angle (RMP), total rearfoot motion angle (TRM), and peak velocity of the rearfoot angle (PV).

In analysing plantar loading, the insole was divided and masked into nine areas according to the human foot anatomy: M1 (medial heel), M2 (lateral heel), M3 (medial midfoot), M4 (lateral midfoot), M5 (first metatarsal head), M6 (second metatarsal head), M7 (third, fourth, and fifth metatarsal heads), M8 (great toe), and M9 (lesser toes), as shown in Figure 2. Similar masks have been used in previous studies (Bontrager, Boyd, Heino, Mulroy, & Perry, 1997; Burnfield, Few, Mohamed, & Perry, 2004; Mao, Li, & Hong, 2006; Wong, Chamari, Mao, Wisløff, & Hong, 2007). Using the Novel Pedar software, parameters such as peak pressure in each mask and contact area in each mask were determined.

### *Data analysis*

All data are presented as means and standard deviations. Paired samples *t*-tests were used to determine whether each dependent variable of the laced running shoes was different from that of the elastic-covered running shoes. The number of dependent variables compared between the laced and elastic-covered running shoes was nine for perceived comfort, four for reafoot motion, and ten for plantar pressure. Statistical significance was set at $P < 0.05$.

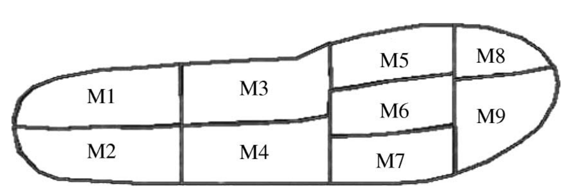


Figure 2. Insole masks. M1 = medial heel, M2 = lateral heel, M3 = medial midfoot, M4 = lateral midfoot, M5 = first metatarsal head, M6 = second metatarsal head, M7 = third, fourth, and fifth metatarsal heads, M8 = great toe, M9 = lesser toes.

## Results

### *Perceived comfort test*

The laced running shoes had better perceived comfort than the elastic-covered running shoes in Q3 (forefoot cushioning, $P = 0.029$), Q6 (heel cup fitting, $P = 0.013$), Q7 (shoe heel width, $P = 0.036$), Q8 (shoe forefoot width, $P = 0.002$), and Q9 (shoe length, $P = 0.013$), as shown in Figure 3.

### *Rearfoot movement test*

There was a lower absolute rearfoot maximal pronation angle for running shoes with shoelaces ($P = 0.013$), indicating that lesser pronation is related to this type of shoes. No significant differences were found in other rearfoot movement variables between elastic-covered shoes and laced running shoes (Table I).

### *Plantar loading*

There was a significantly higher peak pressure on the M7 area (third, fourth, and fifth metatarsal heads) in elastic-covered running shoes than in laced running shoes ($P = 0.005$). No significant difference in peak pressure was observed on other foot sole areas between the two types of shoes (Table II). No significant differences were found in the contact area of each mask (Table II).

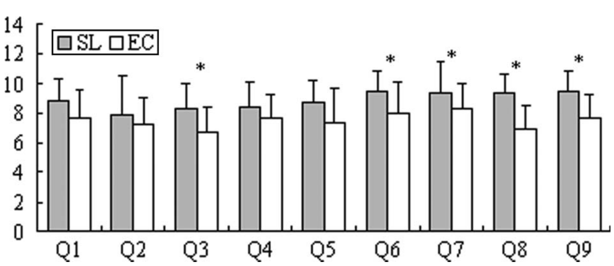


Figure 3. Comparison of the perceived comfort scores between laced running shoes and elastic-covered running shoes. SL = laced running shoes, EC = elastic-covered running shoes. Q1 = overall comfort, Q2 = heel cushioning, Q3 = forefoot cushioning, Q4 = medial–lateral control, Q5 = arch height, Q6 = heel cup fitting, Q7 = shoe heel width, Q8 = shoe forefoot width, Q9 = shoe length. *Significantly different from SL ($P \leq 0.05$).

Table I. Parameters used in rearfoot motion testing (mean values with standard deviations in parentheses).

| | TDR (°) | TRM (°) | RMP (°) | MV (deg · s$^{-1}$) |
|---|---|---|---|---|
| Laced shoes | 6.3 (3.9) | 13.5 (2.7) | −6.6 (2.5) | −381.6 (84.8) |
| Elastic covered | 5.8 (3.7) | 14.2 (3.4) | −7.7 (2.7)* | −359.3 (94.8) |

*Note*: TDR = rearfoot touchdown angle, RMP = rearfoot maximal pronation angle, TRM = total rearfoot motion angle, PV = peak velocity of the rearfoot angle, SL = laced running shoes, EC = elastic-covered running shoes. *$P < 0.05$.

## Discussion

### *Perceived comfort*

Frey (2000) posited that a shoelace allows for a more comfortable shoe fit because runners can adjust the tightness of the shoelace to fit the shape of their foot to obtain custom fit. In Hagen and Henning's study (2009), a questionnaire using a 7-point perception scale was adopted. In the current study, a reliable questionnaire to evaluate running shoe comfort was used. We found that laced running shoes scored higher than elastic-covered running shoes in terms of shoe length, width, and heel cup comfort. Thus, our results support Frey's (2000) assumption that shoelaces may help runners in ensuring that their shoes fit the shape of their feet better.

In this study, elastic-covered running shoes had lower perceived comfort for forefoot cushioning. The pressure distribution of the foot's sole has been found to be associated with comfort (Chen, Nigg, Hulliger, & de Koning, 1995; Milani et al., 1997). A higher plantar pressure would decrease the perceived plantar comfort (Jordan & Bartlett, 1995). Some researchers have used an in-sole plantar pressure system to investigate the cushioning effects of different running shoes (Clinghan et al., 2008; Dixon, 2008; Wegener, Burns, & Penkala, 2008). The higher plantar pressure found in the M7 area (lateral side of the forefoot) in elastic-covered running shoes in this study might have contributed to the lower perceived comfort of forefoot cushioning in this type of shoes. Compared with the shoes with an elastic shoe cover, the shoes with shoelaces showed better comfort in length, forefoot, and heel width, but not in overall comfort. This might be because the two types of shoes showed no difference in terms of the four other comfort ratings. The limited number of participants in this study might be another reason why the shoes with shoelaces showed a moderately ($P = 0.074$), but not significantly, higher overall comfort rating than the elastic-covered shoes.

### *Plantar loading*

In the current study, peak plantar pressure in the M7 area (lateral side of the forefoot) was found to be higher in the elastic-covered running shoes than in the laced running shoes. Comparable results were reported by Hagen and Henning (2009). In their study, the participants were made to wear the same shoes, which were laced in different ways (eyelets 1–2; eyelets 1–6; eyelets 1–7; and eyelets 1, 3, and 5). The lacing pattern using all seven eyelets resulted in the lowest peak pressure, while the weak six-eyelet lacing pattern resulted in the highest peak pressure. The results indicated that the more tightly laced

Table II. Parameters used in plantar load testing (mean values with standard deviations in parentheses).

| | Total | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Peak pressure (kPa) | | | | | | | | | | |
| SL | 367.6 | 214.0 | 215.1 | 96.2 | 124.6 | 308.9 | 279.1 | 204.8 | 317.3 | 195.1 |
| | (65.9) | (37.2) | (41.0) | (20.0) | (23.2) | (84.59) | (59.49) | (46.6) | (88.7) | (34.0) |
| EC | 369.9 | 219.3 | 219.1 | 96.8 | 136.0 | 302.4 | 281.9 | 223.5 | 316.2 | 186.2 |
| | (81.2) | (34.1) | (30.0) | (18.2) | (35.6) | (96.66) | (50.9) | (53.4) | (94.9) | (43.7) |
| *P*-value | 0.847 | 0.364 | 0.537 | 0.884 | 0.073 | 0.64 | 0.669 | 0.005* | 0.918 | 0.326 |
| Contact area ($cm^2$) | | | | | | | | | | |
| SL | 182.2 | 26.3 | 23.5 | 24.1 | 24.5 | 14.9 | 17.8 | 17.7 | 11.4 | 21.9 |
| | (4.6) | (1.4) | (0.4) | (2.7) | (0.0) | (0.8) | (0.50) | (0.2) | (0.2) | (0.6) |
| EC | 182.9 | 26.5 | 23.6 | 24.2 | 24.5 | 15.0 | 17.7 | 17.7 | 11.4 | 22.2 |
| | (3.0) | (1.1) | (0.3) | (1.5) | (0.0) | (0.8) | (0.6) | (0.3) | (0.1) | (0.2) |
| *P*-value | 0.394 | 0.466 | 0.753 | 0.818 | | 0.873 | 0.406 | 0.483 | 0.426 | 0.073 |

*Note*: M1 = medial heel, M2 = lateral heel, M3 = medial midfoot, M4 = lateral midfoot, M5 = first metatarsal head, M6 = second metatarsal head, M7 = third, fourth, and fifth metatarsal heads, M8 = great toe, M9 = lesser toes, SL = laced running shoes, EC = elastic-covered running shoes. *$P < 0.05$.



shoes (eyelets 1–7 and tighter eyelets 1–6) were linked to lower pressure on the lateral midfoot.

### *Rearfoot motion*

Pronation is defined as a tri-planar motion of the foot and ankle consisting of eversion in the calcaneus, abduction in the forefoot, and dorsiflexion in the ankle (Lafortune, Cavanagh, Sommer, & Kalenak, 1994; Soutas-Little, Beavis, Verstraete, & Markus, 1987). Excessive foot pronation in walking or running is believed to be a serious risk factor for injuries of the lower extremities (Hintermann & Nigg, 1998). It has been reported that a special pronated shoe-lacing technique is effective in controlling the rearfoot motion in soccer players with excessive pronation in normal running (Sandrey et al., 2001). Hagen and Henning (2009) hypothesized that the looser the lacing, the greater the maximum pronation; however, their study did not confirm this hypothesis. Hagen and Henning (2009) also explained that the maximum pronation value in the loosest lacing condition (two-eyelet lacing pattern) could not be detected because the fitting between the heel and the heel counter was not maintained. In the current study, elastic-covered running shoes showed a larger maximum eversion than laced running shoes. It is therefore suggested that a shoelace structure helps fit the heel and the heel counter, thus contributing to the control of rearfoot motion.

It has been reported that less pronation is associated with a higher plantar pressure on the lateral side and a lower plantar pressure on the medial side of the foot (O'Sullivan, Kennedy, O'Neill, & Ni Mhainin, 2008; Willems et al., 2006). In this study, the lower absolute rearfoot maximal pronation angle and lower peak plantar pressure in the M7 area (lateral side of the forefoot) was associated with laced running shoes, which supports previous findings.

As mentioned above, footwear has been linked to the prevention of injuries and to increased comfort in running (McKenzie et al., 1985; Riddle et al., 2003; Taunton et al., 2003). Avramakis and co-workers (Avramakis, Stakoff, & Stüssi, 2000) demonstrated that the shoe shaft and shoe sole height influences lateral movement of the foot and ankle complex and the stabilizing effect of the shoe upper with respect to supination. In the current study, the better perceived comfort, lower absolute rearfoot maximal pronation angle, and lower peak plantar pressure were associated with laced running shoes. Compared with elastic-covered running shoes, laced running shoes may help prevent injury in running by controlling the aforementioned factors.

One of the limitations of this study is that only two types of running shoe were evaluated. Although we tested plantar pressure in running, the pressure of the foot dorsum was not measured; thus, we are not able to discuss the changes in the pressure of the foot dorsum in the two types of shoes studied. Nevertheless, changes in the pressure of the foot dorsum could provide more information on the value of shoelaces (Hagen et al., 2010). The effects of shoe lacing may be a function of shoe designs. This study used only X-lacing; other special shoe-lacing patterns (Frey, 2000) were not studied. A two-dimensional (2D) video analysis technique was used to determine the rearfoot movement. Although this 2D video analysis technique has been widely used in previous literature for this purpose (Cheung & Ng, 2007; Clarke, Frederick, & Hamill 1983; DeWit et al., 1995; Hamill et al., 1992), this technique only reflects the rearfoot movement in the participant's frontal plane, which does not always coincide with the plane in which inversion and eversion occur. Thus, the data obtained in this study only allow a preliminary comparison of the two types of shoe. Three-dimensional video analysis techniques are recommended for future study.

## Conclusion

Shoelaces help runners to achieve better foot–shoe fit. They also increase the perceived comfort, and decrease the maximum pronation and plantar pressure. Moreover, they may help prevent injury in running by controlling the aforementioned factors. Therefore, shoelaces play a vital role in running. A shoelace system, or any other system that can secure the foot within the footbed and heel counter, must be necessarily integrated in running shoes.



## References


American Society for Testing and Materials (2006). *Standard test method for comparison of rearfoot motion control properties of running shoes*, ASTM F1833. West Conshohocken, PA: ASTM.

Avramakis, E., Stakoff, A., & Stüssi, E. (2000). Effect of shoe shaft and shoe sole height on the upper ankle joint in lateral movements in floorball (uni-hockey). *Sportverletzung Sportschaden*, *14*, 98–106.

Bontrager, E. L., Boyd, L. A., Heino, J. G., Mulroy, S. J., & Perry, J. (1997). Determination of novel pedar masks using Harris mat imprints. *Gait and Posture*, *5*, 167–168.

Burnfield, J. M., Few, C. D., Mohamed, O. S., & Perry, J. (2004). The influence of walking speed and footwear on plantar pressures in older adults. *Clinical Biomechanics*, *19*, 78–84.

Cavanagh, P. R., & Lafortune, M. A. (1980). Ground reaction forces in distance running. *Journal of Biomechanics*, *13*, 397–406.

Chen, H., Nigg, B. M., Hulliger, M., & de Koning, J. (1995). Influence of sensory input on plantar pressure distribution. *Clinical Biomechanics*, *10*, 271–274.

Cheung, R. T. H., & Ng, G. Y. F. (2007). Efficacy of motion control shoes for reducing excessive rearfoot motion in fatigued runners. *Physical Therapy in Sport*, *8*, 75–81.

Chiu, M. C., & Wang, M. J. (2007). Professional footwear evaluation for clinical nurses. *Applied Ergonomics*, *38*, 133–141.

Clarke, T. E., Frederick, E. C., & Hamill, C. L. (1983). The effects of shoe design parameters on rearfoot control in running. *Medicine and Science in Sports and Exercise*, *15*, 376–381.

Clinghan, R., Arnold, G. P., Drew, T. S., Cochrane, L. A., & Abboud, R. J. (2008). Do you get value for money when you buy an expensive pair of running shoes? *British Journal of Sports Medicine*, *42*, 189–193.

DeWit, B., DeClercq, D., & Lenoir, M. (1995). The effect of varying midsole hardness on impact forces and foot motion during foot contact in running. *Journal of Applied Biomechanics*, *11*, 395–406.

Dixon, S. J. (2008). Use of pressure insoles to compare in-shoe loading for modern running shoes. *Ergonomics*, *51*, 1503–1514.

Fox, K., & Rickards, L. (2004). *National statistics, Sport and Leisure General Household Survey 2002*. London: The Office for National Statistics.

Frey, C. (2000). Foot health and shoewear for women. *Clinical Orthopaedics and Related Research*, *372*, 32–44.

Hagen, M., & Henning, E. M. (2008). The influence of different shoe lacing conditions on plantar pressure distribution, shock attenuation and rearfoot motion in running. *Clinical Biomechanics*, *23*, 673–674.

Hagen, M., & Henning, E. M. (2009). Effect of different shoe-lacing patterns on the biomechanics of running shoes. *Journal of Sports Sciences*, *27*, 267–275.

Hagen, M., Homme, A., Umlauf, T., & Henning, E. M. (2010). Effects of different shoe-lacing patterns on dorsal pressure distribution during running and perceived comfort. *Research in Sports Medicine*, *18*, 176–187.

Hamill, J., Bates, B. T., & Holt, K. G. (1992). Timing of lower extremity joint actions during treadmill running. *Medicine and Science in Sports and Exercise*, *24*, 807–813.

Hamill, J., Moses, M., & Seay, J. (2009). Lower extremity joint stiffness in runners with low back pain. *Research in Sports Medicine*, *17*, 260–273.

Henning, E. M., & Milani, T. L. (1995). In-shoe pressure distribution for running in various types of footwear. *Journal of Applied Biomechanics*, *11*, 299–310.

Hintermann, B., & Nigg, B. M. (1998). Pronation in runners: Implications for injuries. *Sports Medicine*, *26*, 169–176.

Hong, W. H., Lee, Y. H., Chen, H. C., Pei, Y. C., & Wu, C. Y. (2005). Influence of heel height and shoe insert on comfort perception and biomechanical performance of young female adults during walking. *Foot and Ankle International*, *26*, 1042–1048.

Jordan, C., & Bartlett, R. (1995). Pressure distribution and perceived comfort in casual footwear. *Gait and Posture*, *3*, 215–216.

Kersting, U. G., & Brüggemann, G. P. (2006). Midsole material-related force control during heel–toe running. *Research in Sports Medicine*, *14*, 1–17.

Lafortune, M. A., Cavanagh, P. R., Sommer, H. J., III, & Kalenak, A. (1994). Foot inversion–eversion and knee kinematics during walking. *Journal of Orthopaedic Research*, *12*, 412–420.

Lysholm, J., & Wiklander, J. (1987). Injuries in runners. *American Journal of Sports Medicine*, *15*, 168–171.

Mao, de W., Li, J. X., & Hong, Y. (2006). Plantar pressure distribution during Tai Chi exercise. *Archives of Physical Medicine and Rehabilitation*, *87*, 814–820.

McKenzie, D. C., Clement, D. B., & Taunton, J. E. (1985). Running shoes, orthotics, and injuries. *Sports Medicine*, *2*, 334–347.

Milani, T. L., Hennig, E. M., & Lafortune, M. A. (1997). Perceptual and biomechanical variables for running in identical shoe constructions with varying midsole hardness. *Clinical Biomechanics*, *12*, 294–300.

Mündermann, A., Stefanyshyn, D. J., & Nigg, B. M. (2001). Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Medicine and Science in Sports and Exercise*, *33*, 1939–1945.

Nigg, B. M., & Morlock, M. (1987). The influence of lateral heel flare of running shoes on pronation and impact forces. *Medicine and Science in Sports and Exercise*, *19*, 294–302.

O'Sullivan, K., Kennedy, N., O'Neill, E., & Ni Mhainin, U. (2008). The effect of low-dye taping on rearfoot motion and plantar pressure during the stance phase of gait. *BMC Musculoskeletal Disorders*, *9*, 111.

Polster, B. (2002). Mathematics: What is the best way to lace your shoes? *Nature*, *420*, 476.

Riddle, D. L., Pulisic, M., Pidcoe, P., & Johnson, R. E. (2003). Risk factors for plantar fasciitis: A matched case-control study. *Journal of Bone and Joint Surgery*, *85A*, 872–877.

Sandrey, M. A., Zebas, C. J., & Bast, J. D. (2001). Rear-foot motion in soccer players with excessive pronation under 4 experimental conditions. *Journal of Sport Rehabilitation*, *10*, 143–154.

Soutas-Little, R. W., Beavis, G. C., Verstraete, M. C., & Markus, T. L. (1987). Analysis of foot motion during running using a joint co-ordinate system. *Medicine and Science in Sports and Exercise*, *19*, 285–293.

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2003). A prospective study of running injuries: The Vancouver Sun Run "In Training" clinics. *British Journal of Sports Medicine*, *37*, 239–244.

Verdejo, R., & Mills, N. J. (2004). Heel–shoe interactions and the durability of EVA foam running-shoe midsoles. *Journal of Biomechanics*, *37*, 1379–1386.

Walter, S. D., Hart, L. E., McIntosh, J. M., & Sutton, J. R. (1989). The Ontario cohort study of running-related injuries. *Archives of Internal Medicine*, *149*, 2561–2564.

Wegener, C., Burns, J., & Penkala, S. (2008). Effect of neutral-cushioned running shoes on plantar pressure loading and comfort in athletes with cavus feet: A crossover randomized controlled trial. *American Journal of Sports Medicine*, *36*, 2139–2146.

Willems, T. M., De Clercq, D., Delbaere, K., Vanderstraeten, G., De Cock, A., & Witvrouw, E. (2006). A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait and Posture*, *23*, 91–98.

Wong, P. L., Chamari, K., Mao, de W., Wisløff, U., & Hong, Y. (2007). Higher plantar pressure on the medial side in four soccer-related movements. *British Journal of Sports Medicine*, *41*, 93–100.