Wolters Kluwer Health | Lippincott Williams & Wilkins
MEDICINE & SCIENCE IN SPORTS & EXERCISE®
Official Journal of the American College of Sports Medicine

Shoe inserts and orthotics for sport and physical activities

Author(s): NIGG, BENNO M.; NURSE, MATTHEW A.; STEFANYSHYN, DARREN J.
ISSN: 0195-9131
Accession: 10416543
Issue: Volume 31(7) Supplement, July 1999, pp S421-S428
Publication Type: [Clinical Supplement: Foot And Ankle]
Publisher: © 1999 Lippincott Williams & Wilkins, Inc.
Institution(s): Human Performance Laboratory, Faculty of Kinesiology, The University of Calgary, Calgary, CANADA
Submitted for publication September 1998.
Accepted for publication February 1999.
Address for correspondence: Benno M. Nigg, Dr.sc.nat., Human Performance Laboratory, Faculty of Kinesiology, The University of Calgary, 2500 University Drive NW, Calgary, Alberta, Canada T2N 1N4. E-mail: uheinz@ucalgary.ca.

Keywords: Athletic Injuries, Biomechanics, Equipment Design, Feedback, Foot, Gait, Humans, Orthotic Devices, Posture, Sensory Thresholds, Shoes

ABSTRACT

Shoe inserts and orthotics for sport and physical activities. *Med. Sci. Sports Exerc.*, Vol. 31, No. 7(Suppl.), pp. S421-S428, 1999. The purposes of this paper were to discuss the perceived benefits of inserts and orthotics for sport activities and to propose a new concept for inserts and orthotics. There is evidence that inserts or orthotics reduce or prevent movement-related injuries. However, there is limited knowledge about the specific functioning an orthotic or insert provides. The *same orthotic or insert is often proposed for different problems.* Changes in skeletal movement due to inserts or orthotics seem to be small and not systematic. Based on the results of a study using bone pins, one may *question the idea that a major function of orthotics or inserts consists in aligning the skeleton.* Impact cushioning with shoe inserts or orthotics is typically below 10%. Such small reductions might not be important for injury reduction. It has been suggested that changes in material properties might produce *adjustments in the muscular response* of the locomotor system. The foot has various sensors to detect input signals with subject specific thresholds. Subjects with *similar sensitivity threshold levels* seem to respond in their movement pattern in a similar way. Comfort is an important variable. From a biomechanical point of view, comfort may be related to fit, additional stabilizing muscle work, fatigue, and damping of soft tissue vibrations. Based on the presented evidence, the concept of *minimizing muscle work* is proposed when using orthotics or inserts. A force signal acts as an input variable on the shoe. The shoe sole acts as a first filter, the insert or orthotic as a second filter, the plantar surface of the foot as a third filter for the force input signal. The filtered information is transferred to the central nervous system that provides a subject specific dynamic response. The subject performs the movement for the task at hand. For a given movement task, the skeleton has a preferred path. If an intervention supports/counteracts the preferred movement path, muscle activity can/must be reduced/increased. Based on this concept, an optimal insert or orthotic would reduce muscle activity, feel comfortable, and should increase performance.

Shoe inserts and orthotics for sport and other physically intensive activities have been advocated and successfully used for many years. They have been used for patients with diabetes (24,25,35), adjustment of flat feet (27), compensation for osteoarthritic knees (46), and treatment or prevention of rheumatoid foot disease (19,56). However, inserts and orthotics are also used for physical activity and sport. Their administration or prescription has been and is done for many different reasons, including

* to reduce the frequency of movement-related injuries,
* to align the skeleton properly,
* to provide improved cushioning,
* to improve the sensory feedback, and/or
* to improve comfort.

The purposes of this article are to discuss these perceived benefits of shoe inserts and orthotics for sport and physically intensive activities and to propose a new concept for further improvement of insert and orthotic development.

PROPOSED BENEFITS OF SHOE INSERTS AND ORTHOTICS

The listed goals of shoe inserts and/or orthotics may be based on scientific data, on clinical evidence and experience, on functional thinking, and/or on tradition or "gut feeling." This section will discuss critically the perceived benefits of shoe inserts and orthotics listed above.

Reduction of the frequency of injuries. One of the most common reasons for the prescription and use of an insert or orthotic is the desire to act against a developing injury or to avoid a typical movement-related injury. Several studies have reported successful interventions with orthotics or inserts in sport activities. In the average, the literature reports that between 70% and 80% respond positively to treatment to a variety of injuries with orthotics or inserts. It has been proposed that the positive result may not be due to a correction of an underlying biomechanical deficit (21).

James and coworkers (23) used rigid or flexible orthotics for runners with knee injuries. Of the treated runners, 78% were able to return to their previous running program. Analysis of six of the successfully treated runners showed that the orthotics had reduced the maximum and the duration of foot eversion for these runners (3).

Another study synthesized data from runners in a sport medical center over a 5-yr period (9,10). Its authors came to the conclusion that properly fitted orthoses reduce the frequency of running injuries and that the used orthoses did not address the "malalignment" of cavus feet.

Donatelli and coworkers (12) assessed, through a post-treatment survey, selected effects of semirigid plastic or fiberglass orthotics to treat knee pain, ankle pain, shin splints, or chondromalacia. Most (96%) patients experienced relief from pain, and 70% were able to return to previous levels of activity. Gross and coworkers (20) conducted a survey of long-distance runners using orthotic shoe inserts to counter excessive foot eversion (31.1%), plantar fasciitis (20.7%), Achilles tendinitis (18.5%), leg length discrepancy (13.5%), patellofemoral disorders (12.6%), and shin splints (7.2%). Of the 347 respondents, 76% reported complete recovery or substantial improvement in symptoms due to the orthotics.

An excellent study analyzed the effect of foot arch structure and a specific orthotic device on the occurrence of stress fractures on military recruits (57). They showed that the frequency of movement-related stress fractures depended on the foot structure. Femoral and tibial stress fractures were more frequent in subjects with high-arched feet. Metatarsal stress fractures were more frequent for subjects with low foot arches. The use of a semirigid orthotic device (Langer military stress orthotic) reduced the stress fracture incidence only for specific groups. Femoral stress fractures were only reduced for subjects with high arches, metatarsal stress fractures only for subjects with low arches. However, the authors did not provide a functional explanation for these extremely interesting results.

These and many other publications (15,19,21,46) implied directly or indirectly that inserts or orthotics reduce or prevented movement-related injuries. The most important aspects of these publications relating to the reduction of the frequency of injuries can be summarized as follows:

* There is evidence that selected orthotics improve the injury situation of runners and athletes in general.
* There is limited knowledge about the specific function an orthotic or insert provides, which is used to limit excessive loading of specific structures.
* It is interesting to notice that the *same orthotic or insert device has been proposed for many different problems and injuries.*

Aligning the skeleton. Many sports-related injuries have been associated with biomechanical deficits such as the static or dynamic malalignment of the skeleton. Excessive foot varus or valgus *positions* have been associated with creating high-loading situations and for repeated loading cycles overuse injuries. Additionally, excessive foot eversion and/or tibial rotation *movements* have been proposed to increase the chance of overuse syndromes such as patellofemoral pain syndromes, shin splints, Achilles tendinitis, plantar fasciitis, and stress fractures (5,8,23). Through the subtalar joint, the inversion/eversion movement of the calcaneus is translated into external/internal rotation of the tibia (22). Thus, knee injuries have been proposed to develop when excessive foot eversion occurs in conjunction with a strong movement coupling between the foot and the leg (42).

It was in this context that the proper alignment of the skeleton has been proposed as one of the most important functions of shoe inserts and orthotics. It has been proposed that overuse injuries due to excessive foot and leg movement, specifically due to excessive foot eversion, could be reduced with special shoe inserts or orthotics by correcting or limiting the skeletal movement of foot and leg. The postulated effects of such interventions were documented in clinical studies with the treatment and rehabilitation as the variables of interest and in biomechanical studies with the changes in foot and leg movement as the variables of interest.

Nigg and coworkers (38) studied the effect of a medial arch support, with its location systematically changed from posterior (under the sustentaculum tali) to anterior (under the highest point of the longitudinal arch). The results of this study (Fig. 1) showed a reduction of foot and leg movement when comparing the movement with and without orthotics. The largest reduction was achieved with the medial support under the sustentaculum tali. The mean reduction from the condition with no medial support was about 4° for the initial shoe eversion, [DELTA][gamma]$_{10}$ (angle between the heel of the shoe and the ground), and about 5° for the initial leg eversion, [DELTA][beta]$_{10}$ (angle between the heel of the shoe and the long axis of the leg). However, no significant changes were reported for the total foot eversion, [DELTA][beta]$_{tot}$. These results were later confirmed for a series of running shoes with systematically changed midsole hardness and lateral flare (39).

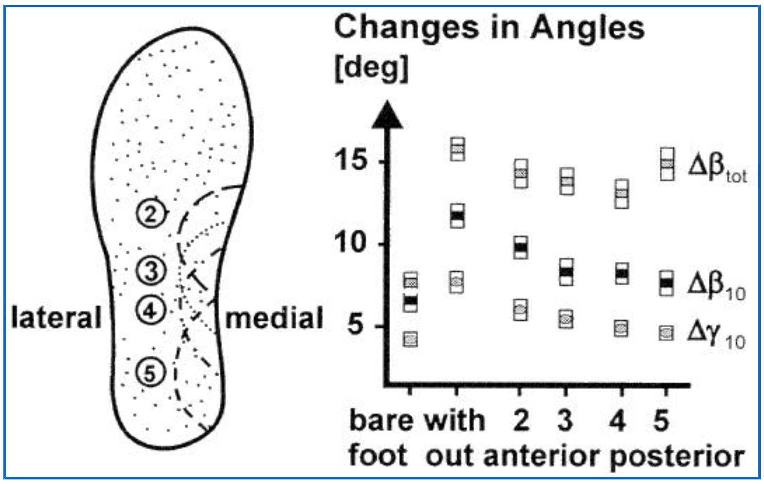

Figure 1-Effect of the location of a medial arch support on initial and total foot eversion movement (from ref. 38. Nigg, B. M., A. H. Bahlsen, J. Denoth, S. M. Luethi, and A. Stacoff. Factors influencing kinetic and kinematic variables in running. In: *Biomechanics of Running Shoes,* B. M. Nigg (Ed.). Champaign, IL: Human Kinetics Publishers, 1986; with permission).

Novick and Kelley (44) examined the effects of rigid orthotics with postings in the fore- and rear-foot. They measured an average decrease in the maximal calcaneal eversion position with respect to the lower leg, as well as a decrease in the total range of inversion/eversion motion due to the tested orthotics. Smith and coworkers (59) studied how runners who regularly wore orthotics responded to semirigid and soft orthotics. They found a significant reduction in maximal calcaneal eversion for semirigid orthotics and a significant reduction in velocity of pronation for both soft and semirigid orthotics. Baitch and coworkers (1) conducted a study on rigid foot orthotic design to compare a flat orthotic with one that forced the foot into 25° inversion. The 25° inverted insole reduced the maximal calcaneus-to-tibia eversion angle compared with the flat insole. It has been suggested that rigid inserts are necessary for precise control of abnormal foot motion. However, results of some studies have suggested that the use of soft orthotics can control joint motion enough to reduce symptoms while providing more cushioning (14,20).

McCulloch and coworkers (31) conducted a study on ten subjects who regularly wore orthotics to control excessive eversion due to forefoot varus. They found that the mean maximal rearfoot eversion (position) was reduced from 10.30° with no orthotics to 6.95° with orthotics. However, they did not measure a significant difference in the total range of eversion or inversion movement with the use of the orthotic. Thus, it was speculated that the difference in the maximal rearfoot eversion position was due to a general shift of the position of the foot toward inversion. Eng and Pierrynowski (14) reported a reduction of 1-3° in the ineversion range of motion through soft foot orthotics on female adolescents suffering from patellofemoral pain syndrome who had previously been diagnosed as having excessive foot eversion during walking and running. Nawoczenski and coworkers (36) quantified the effect of a semirigid foot-orthotic on three-dimensional lower leg kinematics and reported a mean reduction of 2° in internal tibial rotation due to the orthotic. However, they did not find any differences for foot eversion. They suggested that the best effect of orthotics is found in the first half of ground contact.

These and many other publications imply directly or implicitly that inserts or orthotics change (align) the skeletal movement or position. By doing so, it was speculated that they reduce excessive loading in certain structures and consequently reduce movement-related injuries. However, based on alignment measurements (61) on a group of runners enrolling in a marathon training program, the lower-extremity alignment was found not to be a major risk factor for running injuries. Because this study used subjects with a distance of less than 20 km·wk^{-1}, this study may not be powerful to describe the interaction between alignment and injuries.

Additionally, initial results from a prospective study in our lab with 131 runners and an average running distance of 30 km·wk^{-1}, foot and ankle joint alignment did not result as a predictor for an increase in running injuries over a 6-month period.

There may be methodological problems with the data typically presented when alignment was quantified. All insert or orthotic-related studies that quantified changes in alignment used shoe or skin mounted markers. However, results of a recent study (47) showed that shoe markers did not represent the actual skeletal movement of the calcaneus well. Errors introduced by shoe markers compared with bone markers were substantial but not systematic. Errors due to skin markers at the tibia were smaller but still not systematic. Consequently, *alignment of the skeleton* due to the use of shoe orthotics or inserts derived from studies with shoe and skin mounted markers may not be correct and conclusions from such studies should be regarded with caution.

Additionally, a recent study from our group analyzed the effect of two anteriorly and posteriorly located medial supports (38) on the skeletal movement of the calcaneus, the tibia and the femur using bone pins (60). Subjects ran barefoot, with a normal running shoe with no medial support and with the same running shoe using the specially designed shoe inserts with the medial support. The results of this study (Fig. 2) showed no significant differences in the calcaneus and tibia movement during ground contact. The kinematic differences between these four conditions were small (typically below 2°) and not systematic. It is obvious that these results produce more questions than answers. However, the fact that there were no significant or systematic trends between running barefoot, with shoes, and with shoes with orthotics suggests that the concept of aligning the skeleton should be reconsidered.

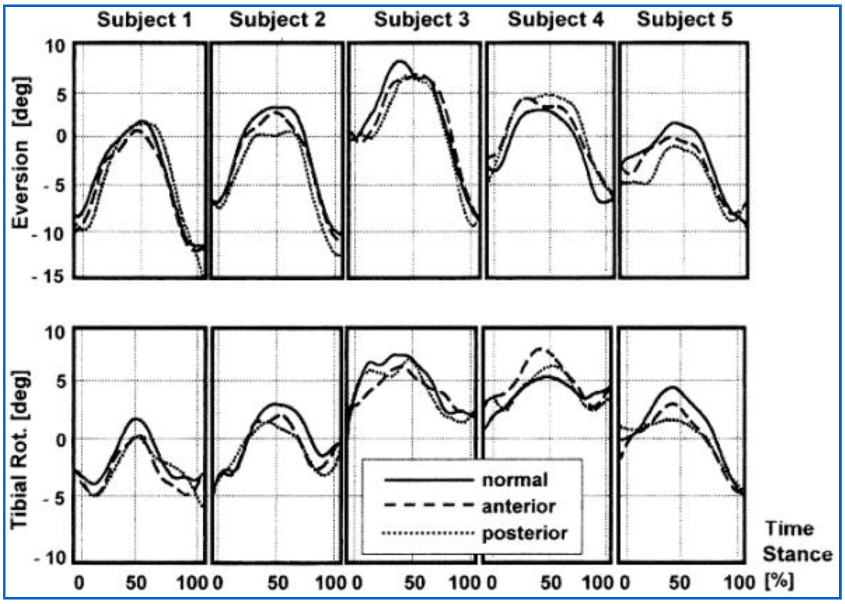

Figure 2-Illustration of calcaneal in-eversion and tibial rotation for five subjects with Hofmann pins in the calcaneus and tibia for inserts with no, anterior, and posterior medial support (from ref. 60. Stacoff, A. P. Skeletal lower extremity motions during running. Doctoral dissertation. University of Calgary, Department of Medical Science, Calgary, Alberta, Canada, August 1998; with permission).

Based on these considerations, conclusions about the ability of inserts or orthotics to align the skeleton are associated with a substantial amount of uncertainty. Based on the results of the bone pin study (60) one may even *question the idea that a major function of orthotics or inserts consists in aligning the skeleton.*

The most important aspects of publications relating to the alignment of the skeleton can be summarized as follows:

* The reported reduction in total foot eversion with inserts or orthotics were significant but small (2-3°) in some reports and not significant in others for measurement taken with skin and shoe mounted markers. Reported differences for the initial eversion were larger.
* Foot and ankle alignment seems not to be a predictor of increased susceptibility for movement-related injuries.
* Changes in skeletal movement due to shoes or shoe inserts seem to be small and not systematic.

Providing improved impact cushioning. Cushioning of the high-frequency impact forces during landing was and is one of the most often postulated benefits of shoe inserts or orthotics during sport activities. It has been speculated that physical activity-related injuries, especially overuse injuries, can be reduced by using shoe and shoe inserts with appropriate cushioning of impact forces. The influence of neoprene insoles, which are assumed to have a cushioning effect, on the frequency of overuse injuries was studied in a prospective study during 9 wk of basic military training (54). The results of this study documented that the relative incidence of overuse injuries and tibial stress syndrome during 9 wk of basic military training can be significantly and substantially reduced (from 31.9% to 22.8%) by wearing appropriate insoles. These results are supported by the results of another randomized prospective study among 390 recruits during 14 wk of training (34). Recruits training in a modified basketball shoe had a statistically significant lower incidence of impact-related injuries (e.g., metatarsal stress fractures and foot overuse injuries) compared with recruits training in standard infantry boots. However, their overall incidence of overuse injuries was not reduced. The two studies indicate that some inserts may be successful in preventing specific impact-related training injuries. However, these and other studies do not provide a guideline or set rules, which orthotic/insert solution (material and shape) to use for a specific situation.

The postulated improvements are assumed to be associated with a reduction in the impact loading effects. Thus, various inserts and orthotics have been tested with respect to reductions in impact forces or impact accelerations. In a study using a human pendulum controlled impacts were delivered to the right foot of 21 subjects for three (0, 20, and 40°) initial knee angles and three (barefoot, soft and hard EVA foams) interfaces (26). The external impact force and the shock experienced by the subjects' shank were measured simultaneously with a wall-mounted force platform and a skin-mounted accelerometer, respectively. Larger knee flexion at contact reduced the impact force but increased the shock (acceleration) traveling throughout the shank. Softer interfaces produced sizable reductions in both initial leg stiffness and severity of the impact experienced by the lower limb. Force rate of loading was found to be highly correlated (r = 0.95) to limb stiffness. These results were used to suggest that interface interventions be better suited to protect the locomotor system against impact loading than knee angle strategies.

The effects of four different viscoelastic inserts on impact cushioning were compared with the results of conventional insoles for 14 asymptomatic male subjects' (41). The measured differences between viscoelastic inserts and controls in this study were small and statistically not significant. In a single-subject study, the shock attenuating effects of a rigid high-density polyethylene orthotic and a soft Plastazote II orthotic were compared (33). It was found that the soft insert performed, for this specific subject, significantly better than the rigid, high-density insole at attenuating impact during running and walking. Impact attenuation of three different shock absorbing insert materials was compared in material and subject tests (55). A reduction of the impact force peak of about 11% for the best insert material compared with the no insert condition was measured. In average, the differences in impact forces with different shoe inserts or orthotics, if compared with no inserts, were rather small and in the same order of magnitude (<20%) as the differences measured between running shoes with different midsole hardness (37). Furthermore, subject tests continued to provide results that changes in midsole material or insert/orthotic material did not change impact force amplitudes by more than 10-20% (7,13,32,37).

Additionally, a prospective study analyzing the effect of impact loading on the general injury frequency in 131 runners over a period of 6 months did not show any significant difference in injury frequency for subjects with high, medium, and low impact force peaks. However, runners with a high loading rate, $(dF/dt)_{max}$, showed significantly fewer injuries (about 50%) than subjects with a low loading rate (Fig. 3). The results of these studies indicate that "impact" and "impact cushioning" for shoes, inserts, and orthotics are complex phenomena, which are not completely understood yet. It has been suggested that impact signals during normal sport activities such as running or playing tennis provide a signal to the locomotor system, which produces a response, which is primarily muscular (43).

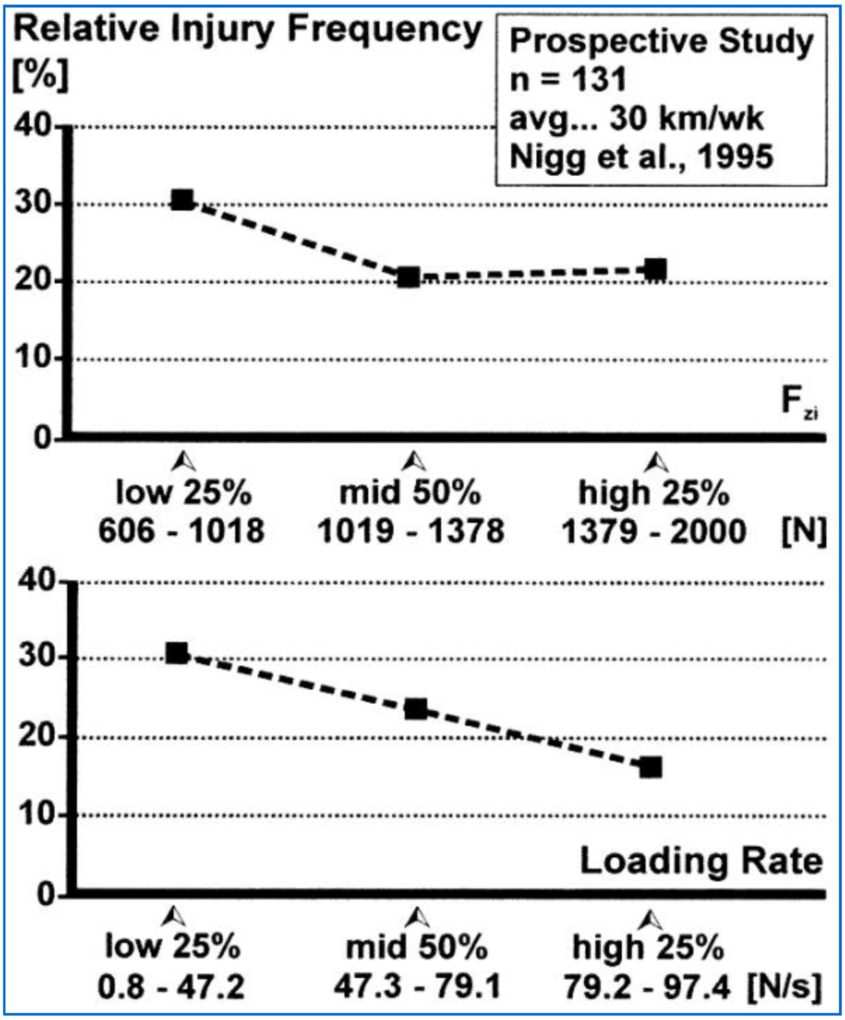

Figure 3-Relative injury frequency for groups with high, medium, and low impact force peaks (*left*) and groups with high, medium, and low maximal loading rate $(df/dt)_{max}$ (from ref. 40 Nigg, B. M., A. Kahn, V. Fisher, and D. Stefanyshyn. Effect of shoe insert construction on foot and leg movement. *Med. Sci. Sports Exerc.* 30:550-555, 1998; with permission).

The most important aspects of these publications relating to the impact cushioning of the skeleton can be summarized as follows:

* Impact cushioning with shoe inserts or orthotics is often present. The typical reduction of impact loading is less than 10-20%.
* It has been questioned whether such small reductions are important for injury reduction and whether impact variations in normal sport activities are responsible at all for increased injury occurrence.
* It has been suggested that changes in material properties of inserts produce adjustments in the muscular response of the locomotor system.

Improving the sensory feedback. Mechanoreceptors in the glabrous skin of the foot provide sensory input into the central nervous system. Receptors arising from Merkel cell complexes are found under the epidermal layer of the skin. They adapt slowly to pressure and maintained deformation of the skin and are sensitive to normal forces against the skin but do not respond to shear stresses (53). In addition, there are mechanoreceptors that respond selectively to vibration. The Meissner corpuscles are located superficially in the skin and respond rapidly to transient movements of the skin between 5 and 40 Hz (30). Pacinian corpuscles are found deeper in the subdermal layer of the skin. They respond quickly to high frequency transient movements of the skin between 60 and 300 Hz (29,53). It is assumed that these mechanoreceptors are involved in the movement response of subjects to shoe-insert-orthotic interventions.

There is general agreement among scientists studying shoe insert and orthotics that each ground contact produces a signal, which is translated in one or another way to a control system to produce a signal response. Differences in opinion exist in the actual functioning of such a system. Interaction between material properties (hard-soft) of shoe soles, inserts, or orthotics have been proposed to influence the movement pattern of athletes. Specifically, it has been proposed that soft materials affect the stability during locomotion negatively and that athletes compensate for this decreased stability with an increase of the impact forces during landing, similarly to hard landings of airplanes in somewhat unstable situations (48-50,51). They suggested that for optimal stability, shoes with thin, hard soles are preferable. The effect of shoes, inserts, and orthotics on balance and stability of an athlete has been attributed to a reduced awareness of foot position (52). Based on these results, they concluded that stability (or balance) and vertical impact are closely related and that instabilities sensed by the foot translate in a change of landing strategies.

Shape and material properties of inserts and orthotics seem to have an important effect on the kinematics and kinetics of actual athletes. Consequently, it is important to quantify shape and material characteristics of actual insert and orthotic products. A method for the quantification of shape has been proposed recently (28). The quantification of material characteristics of inserts and orthotics include the determination of force-deformation characteristics, energy absorption, and frequency-dependent damping (18).

The effect of changes in material properties on foot and leg kinematics was studied using six conditions, one condition in which the movement was performed with the test shoe without any insert and five conditions with specific inserts provided by Schering-Plow Inc. (40). The inserts, constructed to reduce foot eversion and tibial rotation, had a bilayer design using two different materials at the top and bottom of the insert. The foot-leg in-eversion angle, the leg-foot tibial rotation, the arch height, the relative arch deformation (RAD), and the active range of motion (ROM) were quantified. The results of the effects of the tested inserts on foot eversion and internal tibial rotation for four different test subjects are illustrated in Figure 4.

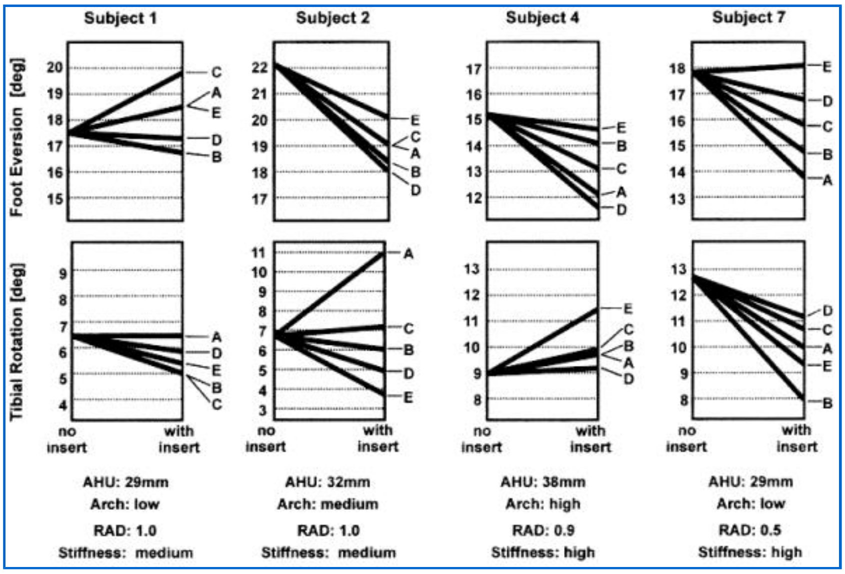

Figure 4-Illustration of the effect of five different shoe inserts on foot eversion (*left box*) and tibial rotation (*bottom box*). The left side of each box shows the mean result for the variable of interest for the no insert condition, the right side for the specific insert conditions. To illustrate the trend, the results for the insert conditions are connected with the results for the no insert condition. Additionally, each subject was characterized with its relative arch deformation, RAD, and its unloaded arch height, AHU. Both characteristics are described with a general assessment such as high, medium or low. (From ref. 40. Nigg, B. M., A. Kahn, V. Fisher, and D. Stefanyshyn. Effect of shoe insert construction on foot and leg movement. *Med. Sci. Sports Exerc.* 30:550-555, 1998; with permission.)

The intervention-related changes were typically less than 4° for foot eversion and below 5° for internal tibial rotation. Each subject showed a different reaction to the five insert interventions. However, there were some group trends. Total tibial rotation decreased for all inserts for 6 of the 12 subjects but increased for all inserts for 3 of the 12 subjects. Subjects with a reduction of total tibial rotation for all inserts had in the average a flexible foot arch (RAD = 1.8) whereas those subjects with an increase of total tibial rotation for all inserts had in the average a stiff foot arch (RAD = 0.57). However, not all subjects could be classified correctly with the selected mechanical subject characteristics. The results of this study could be used to suggest that groups of subjects use a similar signal analysis and response mechanism to react to changes in insert or orthotic materials.

An approach, which took such thinking into account has been presented recently (2) comparing the effects of two insole materials within the shoe using neural network analysis for three different insert conditions: (a) a common shoe, (b) shoe and insert 1, and (c) shoe and insert 2. Pressure data from the plantar surface of the foot (MICRO-EMED system, Novel, Munich, Germany) during walking was used as input into a back-propagation neural network, which was trained to associate sets of pressure-related data with the insert conditions. Subsequently, neural network analysis was performed to reveal the rules that govern the decision-making processes within the neural network, based on the synergistic interactions between the measured variables. The neural network analysis found trends in the way in which the trained neural network responded. The interpretation of those trends provided a description of the kinetic and kinematic responses of the inserts despite the fact that no statistically significant differences were found using a conventional statistical ANOVA test.

This result seems to agree with data of a comparison of foot sensitivity and pressure distribution between the foot and the shoe insert (45). Foot sensitivity was quantified in various areas of the plantar surface of the foot for tactile and vibration sensitivity threshold at 30 and 125 Hz. A significant negative correlation was determined between the foot mean vibration threshold at 125 Hz and the peak force measured during running and the mean vibration threshold of the hallux at 125 Hz and the peak pressures under the hallux while walking and running. The pressure values were low for nonsensitive and high for sensitive feet. This result supports the hypothesis that the foot uses a filtering system to sense input signals and that these input signals are used to develop appropriate movement response strategies.

The most important aspects of publications relating to sensory feedback improvement can be summarized as follows:

* The reaction of subjects to changes in materials of shoe inserts is not consistent and cannot be explained with a simple mechanistic model.
* The foot has various sensors to detect forces and deformations acting on it.
* These sensors detect input signals into the foot with subject specific thresholds.
* Subjects with similar sensitivity threshold levels seem to respond in their movement pattern in a similar way.

Improving comfort. There is no question that shoe inserts and orthotics are often administered to improve the comfort level during a physical activity. However, comfort is a quantity that is difficult to define. Comfort or effects of comfort have been described with psychological, physiological, physical, and safety emphasis (4,16,17,48,58). However, these descriptions and definitions are difficult to implement into shoe insert and orthotic considerations.

Thus, one may want to propose some comfort considerations from a biomechanical point of view.

* Comfort may be related to *fit* of an insert or orthotic. An example for this idea relates to the heel pad. Depending on the heel construction of the insert/orthotic, the heel pad can more or less deform changing its functional role from shock reduction toward local protection of the heel bone (11), a change that is assumed to be related to comfort.
* Comfort may be related to *dynamic stability.* If an insert or orthotic demands *additional muscle work* to maintain a stable movement this insert or orthotic may be considered as not comfortable.
* Additional muscle work to stabilize a situation may also be the reason for *early fatigue,* which may be considered as not comfortable.
* Comfort may also depend on the tendency of soft tissue to vibrate. Every impact produces a shock wave through the locomotor system, which may trigger *soft tissue vibrations.* The muscles must be tuned to avoid such vibration and the muscle tuning may be different for different shoe inserts or orthotics. This additional muscle activity may be considered as not comfortable.

Comfort is extremely important for shoe inserts and orthotics. However, comfort related to shoe inserts and orthotics has not yet been studied in depth. The relationship between plantar pressure distribution under the foot and insole comfort has been discussed recently (6). They reported an increased pressure in the midfoot for comfortable insole situations if compared with less comfortable insoles. However, they did not provide a functional explanation for this result.

In a recent study in our group, a subjective evaluation of short-term insert comfort in military boot was assessed. The 106 subjects tested 10 thin (<4 mm) inserts with systematically changed material and shape properties and classified them based on their subjective comfort feeling. The results of this study showed that subjects differentiated between the inserts and that the assessments were subject specific.

The most important aspects of considerations relating to comfort can be summarized as follows:

* Comfort is extremely important but hard facts on comfort are difficult to find in the scientific literature.
* From a biomechanical point of view comfort may be related to fit, additional stabilizing muscle work, fatigue, and damping of soft tissue vibrations.
* Comfort is a subject specific characteristic.

PROPOSED CONCEPT FOR INSERTS AND ORTHOTICS

The previous section provided a list of facts and speculations, which did often not support the traditional concept that inserts and orthotics are used to align the skeleton. The skeleton seems to change its path of movement for a given task only minimally when exposed to an intervention (shoe, insert, or orthotic). Thus, it seems feasible to propose and discuss the concept of *minimizing muscle work* when using an orthosis or insert. The basic steps of the proposed concept are:

1. Based on the chosen movement a force signal acts as an input variable on the shoe.
2. The shoe sole acts as a first filter for the force input signal.
3. The insert or orthotic acts as a second filter for the force input signal.
4. The plantar surface of the foot with its soft tissue and its mechanoreceptors acts as a third filter for the force-input signal.
5. The filtered information is transferred to the central nervous system that provides a dynamic response based on the subject specific conditions.
6. The subject performs the movement for the task at hand.

The first three steps are situation dependent and can be influenced by the selection of the movement task, the shoe, and the insert or orthotic. The last three steps are subject-dependent. The sensitivity for the mechanical signals, the potentially wobbling soft tissue masses and the cost functions for the movement selection may be different for each situation. Such a concept could explain the experimental results for the skeletal movement (Fig. 1) and for the inserts with changed material properties (Fig. 4). It could also provide a guide along which a podiatrist or orthotist could orient themselves when preparing an orthosis for an athlete or a patient.

If this proposed concept is correct one could conclude that the actual function of an insert or an orthosis is as follows:

* The skeleton has a preferred path for a given movement task (e.g., running).
* If an intervention supports the preferred movement path, muscle activity can be reduced. If an intervention counteracts the preferred movement path, muscle activity must be increased.
* An optimal insert or orthotic reduces muscle activity.
* An optimal insert feels comfortable because muscle activity and the resulting fatigue are minimized.
* Since muscle activity is minimized, performance should increase with an optimal insert/orthotic.

Minimization of muscle activity can occur due to two major strategies. First, by stabilizing joints and second by minimizing soft tissue vibrations (43). The strategies might be effective by treating the incoming input signal or by tuning the muscles for the task at hand.

The presented concept for the function of inserts and orthotics has not been supported by enough experimental and/or theoretical evidence yet. There is some initial experimental evidence in support of it. However, more and stronger evidence must be provided to support or reject the proposed concept. Additionally, it seems imperative that research moves into the direction to determine the signal-response pattern for functional groups of subjects. It should be possible to match subject characteristics (shape, alignment, strength, compliance, sensitivity, etc.) with insert and orthotic characteristics (material properties, shape, time, behavior, etc.) to find the optimal solution for insert/orthotic fitting.

REFERENCES

1. Baitch, S. P., R. L. Blake, P. L. Fineagan, and J. Senatore. Biomechanical analysis of running with 25° inverted orthotic devices. *J. Am. Podiatr. Assoc.* 81:647-652, 1991. [Context Link]

2. Barton, J. A. G., and A. Lees. Comparison of shoe insole materials by neural network analysis. *Med. Biol. Eng. Comput.* 34:453-459, 1996. **Bibliographic Links** | **Library Holdings** | [Context Link]

3. Bates, B. T, L. R. Osternig, B. Mason, and L. S. James. Foot orthotic device to modify selected aspects of lower extremity mechanics. *Am. J. Sports Med.* 7:338-342, 1979. **Bibliographic Links** | **Library Holdings** | [Context Link]

4. Blanch, L. The joys of comfort. *Architect. Dig.* 42:34, 1985. [Context Link]

5. Cavanagh, P. R. *The Running Shoe Book.* Mountain View, CA: Anderson World, Inc., 1980. [Context Link]

6. Chen, H., B. M. Nigg, and J. J. de Koning. Relationship between plantar pressure distribution under the foot and insole comfort. *Clin. Biomed.* 9:335-341, 1994. [Context Link]

7. Clarke, T. E., E. C. Frederick, and C. L. Hamill. Effects of shoe cushioning upon ground reaction forces in running. *Int. J. Sports Med.* 4:247-251, 1983. **Bibliographic Links** | **Library Holdings** | [Context Link]

8. Clement, D. B., J. E. Taunton, G. W. Smart, and K. L. McNicol. A survey of overuse running injuries. *Physician Sportsmed.* 9:47-58, 1981. **Library Holdings**| [Context Link]

9. D'Ambrosia, R. D., and R. Douglas. Orthotics. In: *Prevention and Treatment of Running Injuries,* R. D. D'Ambrosia and D. Drez, Jr. (Eds.), Thorofare, NJ: Slack, 1982, pp. 155-164. [Context Link]

10. D'Ambrosia, R. D. Orthotic devices in running injuries. *Clin. Sports Med.* 4:611-618, 1985. [Context Link]

11. De Clercq, D., P. Aerts, and M. Kunnen. The mechanical characteristics of the human heel pad during foot strike in running: an in vivo cineradiographic study. *J. Biomech.* 27:1213-1222, 1994. **Bibliographic Links**| **Library Holdings**| [Context Link]

12. Donatelli, R., C. Hurlbert, D. Conaway, and R. St. Pierre. Biomechanical foot orthotics: a retrospective study. *J. Orthop. Sports Phys. Ther.* 10:205-212, 1988. **Bibliographic Links**| **Library Holdings**| [Context Link]

13. Dufek, J. S., B. T. Bates, H. P. Davis, and L. A. Malone. Dynamic performance assessment of selected sport shoes on impact forces. *Med. Sci. Sports Exerc.* 23:1062-1067, 1991. **Ovid Full Text**| **Bibliographic Links**| **Library Holdings**| [Context Link]

14. Eng, J., and M. R. Pierrynowski. The effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. *Phys. Ther.* 74:836-844, 1994. **Bibliographic Links**| **Library Holdings**| [Context Link]

15. Fauno, P., S. Kalund, I. Andreasen, and U. Jorgensen. Soreness in lower extremities and back is reduced by use of shock absorbing heel inserts. *Int. J. Sports Med.* 14:288-290, 1993. **Bibliographic Links**| **Library Holdings**| [Context Link]

16. Fisher, V. G., and A. F. Connolly. *Promotion of Physical Comfort and Safety,* 2nd Ed. Dubuque, IA: Wm. C. Brown, 1975, pp. 1-99. [Context Link]

17. Francis, G. V., and B. Munjas. *Promoting Psychological Comfort.* Dubuque, IA: Wm. C. Brown, 1979, pp. 1-105. [Context Link]

18. Garcia, A. C., J. V. Dura, J. Ramiro, J. V. Hoyos, and P. Vera. Dynamic study of insole materials simulating real loads. *Foot Ankle* 15:311-323, 1994. **Library Holdings**| [Context Link]

19. Grifka, J. K. Shoes and insoles for patients with rheumatoid foot disease. *Clin. Orthop. Rel. Res.* 340:18-25, 1997. **Ovid Full Text**| **Bibliographic Links**| **Library Holdings**| [Context Link]

20. Gross, M. L., L. B. Davlin, and P. M. Evanski. Effectiveness of orthotic shoe inserts in the long-distance runner. *Am. J. Sports Med.* 19:409-412, 1991. **Bibliographic Links**| **Library Holdings**| [Context Link]

21. Gross, M. L., and R. C. Napoli. Treatment of lower extremity injuries with orthotic shoe inserts. *Sports Med.* 15:66-70, 1993. **Bibliographic Links**| **Library Holdings**| [Context Link]

22. Inman, V. T. *The Joints of the Ankle.* Baltimore: Williams & Wilkins, 1976, pp. 35-66. [Context Link]

23. James, S. L., B. T. Bates, and L. R. Osternig. Injuries to runners. *Am. J. Sport Med.* 6:40-50, 1978. [Context Link]

24. Kastenbauer, T., G. Sokol, M. Auinger, and K. Irsigler. Running shoes for relief of plantar pressure in diabetic patients. *Diabetic Med.* 15:518-522, 1998. **Bibliographic Links**| **Library Holdings**| [Context Link]

25. Kato, H., T. Takada, T. Kawamura, N. Hotta, and S. Torii. The reduction and redistribution of plantar pressures using foot orthoses in diabetic patients. *Diabetes Res. Cinl. Pract.* 31:115-118, 1996. [Context Link]

26. Lafortune, M. A., E. M. Hennig, and M. J. Lake. Dominant role of interface over knee angle for cushioning impact loading and regulating initial leg stiffness. *J. Biomech.* 29:1523-1529, 1996. **Full Text**| **Bibliographic Links**| **Library Holdings**| [Context Link]

27. Leung, A. K., A. F. Mak, and J. H. Evans. Biomedical gait evaluation of the immediate effect of orthotic treatment for flexible flat foot. *Prosthet. Orthotics Int.* 22:25-34, 1998. [Context Link]

28. Liu, W., J. Miller, D. J. Stefanyshyn, and B. M. Nigg. Accuracy and reliability of a technique for quantifying foot shape, dimensions and structural characteristics. *Ergonomics* 42:346-358, 1999. **Bibliographic Links**| **Library Holdings**| [Context Link]

29. Lynn, B. Cutaneus sensation. In: *Physiology, Biochemistry and Molecular Biology of the Skin,* 2nd Ed. L. Goldsmith.(Ed.). New York: Oxford University Press, 1991, pp. 779-815. [Context Link]

30. Martin, J. H., and T. M. Jessell. Modality coding in the somatic sensory system. In: *Principles of Neural Science,* 3rd Ed. E. R. Kandel, J. H. Schwartz, and T. M. Jessell (Eds.). Norwalk, CT: Appleton & Lange, 1994, pp. 341-352. [Context Link]

31. McCulloch, M., D. Brunt, and D. V. Linden. The effect of foot orthotics and gait velocity on lower limb kinematics and temporal events of stance. *J. Orthop. Sports Phys. Ther.* 17:2-10, 1993. **Bibliographic Links**| **Library Holdings**| [Context Link]

32. McNair, P. J., and R. N. Marshall. Kinematic and kinetic parameters associated with running in different shoes. *Br. J. Sports Med.* 28:256-260, 1994. **Bibliographic Links**| **Library Holdings**| [Context Link]

33. McPoil, T. G., and M. W. Cornwall. Effect of insole material on force and plantar pressures during walking. *J. Am. Podiatr. Med. Assoc.* 82:412-416, 1992. [Context Link]

34. Milgrom, C., A. Finestone, N. Shlamkovitch, J. Wosk, A. Laor, A. Voloshin, and A. Eldad. Prevention of overuse injuries of the foot by improved shoe shock attenuation. A randomized prospective study. *Clin. Orthop. Rel. Res.* 281:189-192, 1992. [Context Link]

35. Müller, M. J., M. J. Strube, and B. T. Allen. Therapeutic footwear can reduce plantar pressures in patients with diabetes and transmetatarsal amputation. *Diabetes Care* 20:637-641, 1997. [Context Link]

36. Nawoczenski, D. A., T. M. Cook, and C. L. Saltzman. The effect of foot orthotics on three-dimensional kinematics of the leg and rearfoot during running. *J. Orthop. Sports Phys. Ther.* 21:317-327, 1995. **Bibliographic Links** | **Library Holdings** | [Context Link]

37. Nigg, B. M., S. M. Luethi, J. Denoth, and A. Stacoff. Methodological aspects of sport shoe and sport surface analysis. In: *Biomechanics VIII-B*, H. Matsui and K. Kobayashi (Eds.). Champaign, IL: Human Kinetic Publishers, pp. 1041-1052, 1983. [Context Link]

38. Nigg, B. M., A. H. Bahlsen, J. Denoth, S. M. Luethi, and A. Stacoff. Factors influencing kinetic and kinematic variables in running. In: *Biomechanics of Running Shoes*, B. M. Nigg (Ed.). Champaign, IL: Human Kinetics Publishers, 1986, pp. 139-159. [Context Link]

39. Nigg, B. M., and M. Morlock. The influence of lateral heel flare of running shoes on pronation and impact forces. *Med. Sci. Sports Exerc.* 19:294-302, 1987. **Ovid Full Text** | **Bibliographic Links** | **Library Holdings** | [Context Link]

40. Nigg, B. M., A. Kahn, V. Fisher, and D. Stefanyshyn. Effect of shoe insert construction on foot and leg movement. *Med. Sci. Sports Exerc.* 30:550-555, 1998. **Ovid Full Text** | **Bibliographic Links** | **Library Holdings** | [Context Link]

41. Nigg, B. M., W. Herzog, and L. J. Read. Effect of viscoelastic shoe insoles on vertical impact forces in heel-toe running. *Am. J. Sport Med.* 16:70-76, 1988. [Context Link]

42. Nigg, B. M., G. K. Cole, and W. Nachbauer. Effects of arch height of the foot on angular motion of the lower extremities in running. *J. Biomech.* 26:909-916, 1993. **Bibliographic Links** | **Library Holdings** | [Context Link]

43. Nigg, B. M. Impact forces in running. *Curr. Opin. Orthop.* 8:43-47, 1997. **Ovid Full Text** | **Library Holdings** | [Context Link]

44. Novick, A., and D. L. Kelley. Position and movement changes of the foot with orthotic intervention during the loading response of gait. *J. Orthop. Sports Phys. Ther.* 11:301-312, 1990. **Bibliographic Links** | **Library Holdings** | [Context Link]

45. Nurse, M. A., and B. M. Nigg. Quantifying a relationship between tactile and vibration sensitivity of the human foot with plantar pressure distribution during gait. *Clin. Biomech.*, in press. [Context Link]

46. Ogata, K., M. Yasunaga, and H. Nomiyama. The effect of wedged insoles on the thrust of osteoarthritic knees. *Int. Orthop.* 21:308-312, 1997. **Bibliographic Links** | **Library Holdings** | [Context Link]

47. Reinschmidt, C., van den Bogert, A. J., Murphy, N., Lundberg, A., and B. M. Nigg. Tibiocalcaneal motion during running: measured with external and bone markers. *Clin. Biomech.* 12:8-16, 1997. [Context Link]

48. Robbins, S. E., and G. J. Gouw. Athletic footwear: unsafe due to perceptual illusions. *Med. Sci. Sports Exerc.* 23:217-224, 1991. **Ovid Full Text** | **Bibliographic Links** | **Library Holdings** | [Context Link]

49. Robbins, S., G. J. Gouw, and J. McClaran. Shoe sole thickness and hardness influence balance in older men. *J. Am. Geriatr. Soc.* 41:1011-1012, 1993. **Library Holdings** | [Context Link]

50. Robbins, S., E. Waked, G. J. Gouw, and J. McClaran. Athletic footwear affects balance in men. *Br. J. Sports Med.* 28:117-122, 1994. **Bibliographic Links** | **Library Holdings** | [Context Link]

51. Robbins, S., and E. Waked. Balance and vertical impact in sports: role of shoe sole materials. *Arch. Phys. Med. Rehabil.* 78:463-467, 1997. **Bibliographic Links** | **Library Holdings** | [Context Link]

52. Robbins, S., E. Waked, P. Allard, J. McClaran, and N. Krouglicof. Foot position awareness in younger and older men: the influence of footwear sole properties. *J. Am. Geriatr. Soc.* 45:61-66, 1997. **Bibliographic Links** | **Library Holdings** | [Context Link]

53. Rothwell, J. *Control of Human Voluntary Movement*, 2nd Ed. New York: Chapman and Hall, 1994, pp. 86-126. [Context Link]

54. Schwellnus, M. P., G. Jordaan, and T. D. Noakes. Prevention of common overuse injuries by the use of shock absorbing insoles: a prospective study. *Am. J. Sports Med.* 18:636-641, 1990. [Context Link]

55. Shiba, N., H. B. Kitaoka, T. D. Cahalan, and E. Y. Chao. Shock-absorbing effect of shoe insert materials commonly used in management of lower extremity disorders. *Clin. Orthop. Rel. Res.* 310:130-136, 1995. **Ovid Full Text** | **Bibliographic Links** | **Library Holdings** | [Context Link]

56. Shrader, J. A., and K. L. Siegel. Postsurgical hindfoot deformity of a patient with rheumatoid arthritis treated with custom-made foot orthoses and shoe modifications. *Phys. Ther.* 77:296-305, 1997. **Bibliographic Links** | **Library Holdings** | [Context Link]

57. Simkin, A., I. Leichter, M. Giladi, M. Stein, and C. Milgrom. Combined effect of foot arch structure and an orthotic device on stress fractures. *Foot Ankle* 10:25-29, 1989. **Bibliographic Links** | **Library Holdings** | [Context Link]

58. Slater, K. *Human Comfort*. Springfield, IL: Charles C Thomas, 1985, pp. 18-88. [Context Link]

59. Smith, L. S., T. E. Clarke, F. Santopietro, and C. L. Hamill. The effects of soft and semi-rigid orthotics upon rearfoot movement in running. *J. Am. Podiatr. Med. Assoc.* 76:227-233, 1986. [Context Link]

60. Stacoff, A. P. Skeletal lower extremity motions during running. Doctoral dissertation. University of Calgary, Department of Medical Science, Calgary, Alberta, Canada, August 1998. [Context Link]

61. Wen, D. Y., J. C. Puffer, and T. P. Schmalzried. Lower extremity alignment and risk of overuse injuries in runners. *Med. Sci. Sports Exerc.* 29:1291-1298, 1997.

Ovid Full Text | **Bibliographic Links** | **Library Holdings** | [Context Link]

Key Words: INSERT; ORTHOTIC; FOOT SENSITIVITY; ALIGNMENT OF SKELETON; SIGNAL FILTERING; MOVEMENT RESPONSE

Copyright (c) 2000-2008 Ovid Technologies, Inc.
Version: OvidSP_UI02.00.03.102, SourceID 37507