NATURAL MOTION – AIM OR ORIGIN FOR FUTURE FOOTWEAR DESIGN

Gert-Peter Brüggemann

Institute of Biomechanics and Orthopedics, German Sport University Cologne, Germany

INTRODUCTION: Influenced by the fitness and running boom in the last three decades, athletic footwear established from simple shoes to a high tech product. New designs, manufacturing techniques and materials were introduced into the construction of technical athletic shoes. This development was further influenced by biomechanical and orthopedic research which supported the establishment of functional concepts and designs. Functional factors (comfort, performance and injury prevention) and also less-functional factors (e.g. price, fashion, and durability) are relevant for the design of athletic footwear.
Millions of people are involved in court activities, running and jogging activities. From the runners, it is reported that between 37-56% are injured during the period of one year. Pre injuries, excessive training volume, training mistakes, excessive impact forces, excessive pronation or excessive knee joint moments (adduction-abduction moments, external rotation moments) have been proposed as major reasons for the development of overuse injuries. Footwear and sport surface were assumed to influence impact forces, foot pronation and knee joint moments. Ankle sprains are one the most frequent acute injuries in sports related activities. It was speculated that appropriate footwear is capable to reduce the risk of over-supination and injuries of the ankle joint complex. Concepts of "impact cushioning" and "motion control" were developed, and strategies were studied to reduce potentially the impact forces and foot pronation through appropriate athletic footwear, shoe inserts, and sport surface designs. However, results of recent studies challenged the proposed association between impact forces, foot pronation, and running injuries.
A critically review of injury frequency, injury location and severeness of injuries does not support that the developed technical strategies have been adequate to decrease the risk of injuries in sports through footwear. Probably the concepts did not fit at all or the basic consideration to decrease the amplitude of forces applied to the biological structures or to align the skeleton are principally wrong and thus failed. One can speculate that the purpose of footwear to control foot motion, to align the skeleton and to modify the forces acting of the biological structures should be the improper strategy to decrease the frequency of sport related injuries and/or to enhance performance.
One can also speculate that a deviation from a preferred or natural joint motion, muscle activation and thus force application through footwear may not be benefit able for the joint health and lower extremity performance potential.

NATURAL MOTION: The natural motion should be defined through the preferred path of motion for a given joint with no interference by shoes, orthotics or (stony) artificial surfaces. A natural environment should be short, soft grass or similar surfaces. From that the natural motion of the foot in bare feet condition and its joints or the whole lower extremities can be defined as the motor solution for a given task (e.g. running or cutting) performed on a natural environment (e.g. on short cut grass). The chosen motor solution can be quantified by joints' paths of motion, net joints moments and or muscle activities.
Some well-known international athletes have successfully competed barefoot. Running in bare feet in long distance events is evidently not a barrier to performance at the highest level. Indeed, one can speculate that wearing running shoes probably reduces performance and increases the risk of injury. There are several original research reports on the occurrence and mechanisms of acute and chronic injuries in unshod and shot populations, and a few reports on the energy cost of running with and without shoes. Most are more or less anecdotal reports and not controlled trials of the effect of running in bare feet on simulated or real competitive performance, nor any surveys on the reasons why people do not compete barefoot.

PERFORMANCE: Performance in sports relates to the final result and can be measured by variables such as time, distance or mechanical work. Performance e.g. in running can be quantified as the energy needed for a given distance and speed (e.g. oxygen uptake). Performance in running can be influenced by the shoe through the mass of the shoe, the impact of the shoe to changes the movement pattern, the possibility of the shoe to store and return mechanical energy and the energy loss through the shoe. The higher oxygen consumption in running with shoe of 700g mass was shown to be 4% higher than in bare feet (Flahery 1994). One can speculate that performing barefoot may contribute to better performance due to less additional mass and probable less energy loss through the shoe materials.
Where barefoot and shod populations co-exist injury rates of the lower extremities are substantially higher in the shod populations (Robbins and Hanna 1987). Furthermore, running-related chronic injuries to bone and connective tissue in the lower extremities are rare in developing countries where most people are habitual barefooted (Robbins and Hanna 1987). The association between running injuries and wearing shoes is consistent with the possibility that wearing shoes increases the risk of injury. But other explanations for the association are possible: for example, in developing countries barefoot runners may be to poor to seek medical attention, shod runners may wear bad shoes, wear shoes incorrectly, and cover more miles. Prospective studies and randomized controlled trials of barefoot and shod running would resolve this uncertainty.
Studies of rates of injuries in barefoot and shod runners in developed countries are non-existing, presumably because barefoot runners are a rarity. However, there have been several studies implicating footwear in the etiology of injuries in runners. Latest our prospective study with a minimal shoe (Nike Free) showed a clear decrease of lower extremity injuries in relation to a control group.

OPTIMIZATION OF MUSCLE FUNCTION: When in heel toe running the foot in a shoe with stiff midsole and outer sole hits the ground, the point of application of the ground reaction force is located posterior to the ankle joint. The ground reaction force results in a plantar flexion of the ankle joint which will load the dorsal flexor muscles (e.g. M. tibialis anterior). In addition the plantar flexion leads to a shortening of the muscle tendon unit of the M. triceps surae and to a decrease of the force potential of the contractile element of M. triceps surae. The tension of the Achilles tendon will decrease and the ankle joint coupling will be affected. This phenomenon was experimentally demonstrated using the optic fiber technique and ultrasound measurements (Brüggemann 2001). In natural (barefoot on grass) running the lever arm of the ground reaction force is much smaller than in shod condition at the instant the foot comes to ground. The external plantar flexion moment is substantially smaller and the decoupling of the ankle joint less dramatic. The force vector passes the ankle joint much earlier than in a shod condition. The dorsal flexion moment will be applied earlier and leads to an early stretch of the plantar flexor muscles. This early stretch can also be observed for the knee extensor muscles. Thus leg extensor muscle can act more efficient when the ground reaction force passes the ankle and the knee joint earlier during the stance phase. From these findings the biomechanical concept of soft (but elastic) or even rounded “crash pads” at the lateral rear end of the sole of running shoes has been derived. The concept results in a more natural and more efficient use of the leg extensor muscles and in a more stable ankle joint coupling.

INJURY PREVENTION

Acute injuries: Ankle sprains are the most frequent acute sport injuries, and 90-95% of these injuries are inversion injuries causing partial or complete rupture of the anterior talofibular ligament and occationally of the calcanealfibular ligament (e.g. Stacoff et al. 1996). It is claimed that footwear increase the risk of such sprains, either by decreasing awareness of foot position provided by feetback from the plantar cutaneous mechanoreceptors in

contact with the ground (Robbins et al. 1995), or by increasing the lever arm and consequently the torque around the subtalar joint in a tumble. Siff and Verkhoshansky (1999) reported that running shoes always reduce the proprioceptive and tactile sensitivity. It is remarkable that gymnasts and dancers both groups with high loading of the feet in performing their sports prefer for performing barefoot due to an improved balance by tactile sensation during movement.
The skin of the plantar surface of the foot is more resistant to the inflammatory effect of abrasion than skin from other parts of the body, but stones, glass, nails or needles can still bruising or puncture wounds even when the plantar skin is thickened by adaptation to barefoot activity. Extreme temperature can also cause discomfort, blistering or chill blains. Shoes may play an important role in protection on some courses in some weather conditions.

Chronic injuries: One of the most common chronic injuries in runners is plantar fasciitis, or an inflammation of the ligament running along the sole of the foot. There is some evidence that the normally unyielding plantar fascia acts as the support for the medial arch. Strain on the proximal facial attachment during foot strike may lead to plantar fasciitis (Robbins and Hanna 1987). Barefoot running induces an adaptation that transfers the impact to the yielding musculature (e.g. flexor hallucis longus) (Brüggemann et al. 2005), thus sparing the fascia and accounting for low incidence of plantar fasciitis in barefoot population (Robbins and Hanna 1987). Chronic injuries such as shint splints, ilio-tibial band syndrome and patella pain are attributed to excessive pronation, and sometimes to shock loading of the lower extremity. One has to notice that pronation mostly increases when using running shoes in relation to the barefoot running pattern. Many authors showed that shoes' capacity for shock attenuation and control of pronation is very limited. Another resulting false sense of security may contribute to the risk of injury reasoned that once the natural foot structures are weakened by long-term footwear use, people have to rely on the external support of the footwear, but the support does not match that provided by a well functioning foot.

CONCLUSIONS: Running shoes (and court shoes) appear to increase the risk of ankle sprains, either by decreasing awareness of foot position or by increasing the torque on the ankle joint during a stumble.
Running shoes appear to increase the risk of plantar fasciitis and other chronic injuries of lower extremities by modifying the transfer of shock and load to muscles and supporting structures.
Research is needed to establish why most professional runners do not choose to run barefoot. Concerns about wounds, bruising, thermal injuries or overuse injuries during adaptation period are possibilities.
Running shoes play an important protective role on some courses, in extreme weather conditions, and with certain pathologies of the lower limb.
The former and recent concepts in the design of running or even court shoes did and probably do not fulfill the demands for injury prevention and performance enhancement. The study of motion solutions for different motor tasks on a natural environment may offer a new view to develop more adequate technical strategies for the human foot and the human lower extremity.

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