NEW IDEAS AND CONCEPTS IN SPORT SHOE DEVELOPMENT

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The sport biomechanist is often challenged to 'test performance' during competition and not in the laboratory environment. While ecological validity of data must always be of concern, measurement error (both system, and modelling) and the characteristics of equipment used (manual or automatic?), often mean that data are collected under 'simulated match' conditions. This paper will review the vexing question of laboratory versus field testing from a biomechanical perspective. Current data suggest that for movements involving out of plane rotations, laboratory testing with an opto-reflective system (cluster based model), provides a more accurate measure of elbow angle when compared with the same angle collected with a video-based system (vector model) during a simulated cricket bowling task.

KEY WORDS: running shoes, barefoot running, shoe concepts, shoe development.

INTRODUCTION: Every new season, new sport shoes are on the market and it is sometimes difficult to establish, whether a "new design" is also associated with an improved functionality. This chapter will attempt

- to list a few new functional developments of the recent months and years
- to discuss the new "concepts" or developments with respect to the proposed function and
- to provide experimental evidence for the claims made (if available)

This publication does not claim to be complete in describing every new technology or development on the market. It contains a few new conceptional developments of the last few years that, in the view of the author, provide new functional possibilities or, at least the potential for it.

"BAREFOOT SHOES": Barefoot training has been used by coaches for a long time with the suggestion that barefoot training improves the strength of the overall muscle system and trains the large and the small muscles. This increase in overall muscle strength has been assumed to be associated with a prevention of movement related injuries. Experimental evidence for this concept was provided through a study quantifying the injury frequency of adolescents with and without a wobble board training. The results of this study (Emery et al., 2005) showed that the adolescent test subjects exposed to the wobble board training showed less sport related injuries than the test subjects that were not exposed to this training. It was speculated that the wobble board training strengthens the small and large muscles and provides a more rounded muscle support in the ankle joint.
This concept was further supported in a recent publication (Nigg, 2005) in which the difference between strong and weak small muscles was illustrated, showing that a joint with strong fast reacting small muscles has much smaller joint and insertion forces (Fig. 1, right) than a joint with only slower reacting strong large muscles (Fig 1, left).
The perceived benefits of barefoot training have been used in various shoe designs. Three new designs using different "barefoot concepts" are discussed in this section, the "Feet You Wear" concept, the Nike Free concept and the MBT (Masai Barefoot Technology) concept.

Fig. 1 Illustration of the effect of strong and weak fast reacting small muscles (springs) on forces in the joint and in the attachment locations of the springs (insertion forces).

The Feet You Wear Concept (adidas)

The idea of adidas' "Feet You Wear" concept was to construct a shoe that mimics the ***shape of the human foot***. The human foot is a structure with a rounded shape. By shaping the shoe like a human foot, the "Feet You Wear" shoes produced smaller levers due to the rounded construction of the shoe sole. The concept was first introduced in basketball and prospective epidemiological studies with men teams from the Canadian University Basketball League over a time period of two years showed for the "Feet You Wear" basketball shoes compared to all the other shoes used in this study a significant and substantial reduction of the frequency of injuries (Meeuwisse et al., 1998). The injury rate per 1000 athlete exposures was 7.1 for the Feet You Wear shoes and 11.3 for the remaining shoes in the first year and 7.3 and 9.8 respectively for the second year. Constructional conclusions from the "Feet You Wear" concept are currently used in several Adidas products (the for motion concept).

Nike Free Concept

The Nike Free shoes were developed with the goal to mimic the ***kinematics of barefoot running***. The Nike Free shoes have (a) a wide and relatively soft heel and (b) a flexible forefoot sole construction. The Nike Free running shoe produces a flat foot landing typical for barefoot running. It seems that this result is influenced by the wide heel and that the flat foot landing could not be achieved by using a heel shape similar to the human heel. The flexible forefoot construction increases the contact area of the foot, distributing the pressure over a larger area. Furthermore, it forces the foot to be more active than in a conventional shoe. The results of this increased foot activity with the Nike Free shoe on a sample of 100 test subjects showed a significant decrease in the actual path of motion of the metatarsal-phalangial (MTP) joint during running by 7% and an increase in the flexor strength that can be produced in this "joint" by 20% (Potthast et al., 2005). Currently, to the knowledge of the author, there are no epidemiological data available for the Nike Free shoe concept.

MBT Masai Barefoot Technology Concept

The MBT shoes were developed with the goal to provide a training tool for the foot and leg ***mimicking the feeling of barefoot movement on soft ground***. The MBT shoe is characterized by its rather thick sole with a rounded bottom profile, producing an ***unstable*** base during standing (similar to a wobble board). During standing, this unstable shoe characteristic demands increased muscle activity to remain balanced (Nigg et al., 2005). Thus, the shoe should be considered as a training device, especially for the small muscles of the foot. Indirect evidence for such a training effect has been provided by the more than 100% increase in balance time when using the MBT shoe over a period of three months (Nigg et al., submitted). The fact that muscle activity is constantly alternating seems to reduce the joint loading due to muscle co-contraction. A prospective epidemiological study over three months using subjects with knee joint arthritis showed a 25% decrease in subjective joint pain when wearing the MBT shoe (Nigg et al., accepted).

Overall, shoes developed using a concept of barefoot technology seem to provide a benefit to the athlete, independent on whether it is based on copying the shape of the human foot, the movement during barefoot running or the feeling of barefoot movement on soft ground.

"ENERGY RETURN"

Sport shoes that use the concept of "energy return" have appeared periodically on the market. The theoretical idea behind "energy return" constructions is that energy is stored in the shoe sole during deformation and returned to the athlete during take-off. To be successful with this concept, the returned energy has to be

- large enough to produce a difference,
- must be returned at the right time,
- at the right location and
- with the right frequency (Nigg et al., 2000).

"Energy return shoes" have been produced earlier. However, these shoes have not produced improvements in performance and have disappeared from the market after a short time. Recently, two patents have been filed that may be of interest in this context. The first patent proposes to solve the problem structurally (EMA), the second using a specific material (Power Bounce).

"EMA" (Energy Management Athletics) Concept

The EMA full suspension shoe design is based on two oval shaped springs under the heel and the forefoot (Fig. 2). The concept uses a solution that can, in principle, produce substantial deformation and storage of elastic energy. This is, as initially mentioned, a necessary prerequisite for a possible significant and relevant return of energy. The shoe concept is specifically geared towards running and produces a rather soft and "springy" running experience. The energy balance of prototypes of this new shoe concept has been tested using oxygen consumption measurements on a treadmill. Compared to the New Balance 766 shoe model the EMA prototype showed a significant 2.2% reduction in oxygen consumption (Hettinga et al., 2005). Considering the fact that the NB 766 shoe is an excellent running shoe this 2.2% difference in oxygen consumption for the same task is remarkable.

Fig. 2 Picture of a prototype of the EMA full suspension shoe design with the two oval shaped "springs" under the heel and the forefoot

The "Power Bounce" Concept

The Power Bounce concept uses material properties to achieve a favorable energy balance (not structure as the EMA full suspension shoe design). The Power Bounce concept uses dilatant compounds in the midsoles. These materials are soft and pliable under slowly applied forces, but become increasingly elastic under more rapidly applied force. It is proposed by the inventor that shoes with a dilatant compound in the midsole are soft and shock absorbing at slow speeds, yet become springy to return energy at faster speeds. Energy balance tests have not been performed yet with these shoes. However, as mentioned before, to have a substantial effect on the energy balance one needs a substantial deformation of the shoe sole and this is typically difficult to achieve by deforming a material. Thus, the author would be surprised if enough energy could be returned with this concept to make a difference in performance.

REAR FOOT CONTROL

Rear foot control is a concept that has been developed in the early days of sport shoe research (Nigg et al., 1977; James et al., 1978; Cavanagh, 1980; Clement et al., 1981; Clarke et al., 1983; Nigg et al., 1983). A sequence of pictures of a runner with and without shoes shows relative little eversion (rotational movement) between the calcaneus and the lower leg for the barefoot condition but sometimes quite substantial eversion for the shod condition (Fig. 3). Sport shoe researchers have realized early on that this increase of eversion in the ankle joint complex was a result of the sometimes rather bulky heel constructions of the running shoes. Despite this understanding, sport shoe manufacturers still continued to produce bulky heel constructions in running and other sport shoes. However, they also attempted to counteract the sometimes excessive eversion by using special shoe constructions.

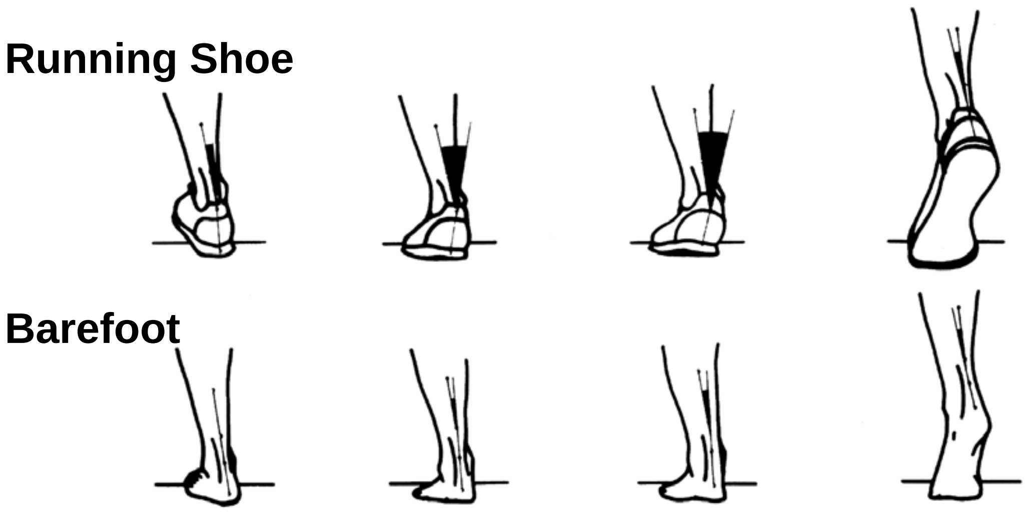

Fig. 3 Illustration of foot eversion for the same person, running barefoot and in running shoes at a running speed of 4 m/s.

Two such attempts are discussed in the following section, the Ground Control System by adidas and the Gel Komodo by Asics.

Ground Control System (GCS) by adidas

The Ground Control System, first developed for the heel in running shoes, uses a heel that can move horizontally with respect to the rest of the shoe during the landing process (Fig. 4). The relative horizontal movement of part of the heel influences the horizontal components of the ground reaction forces. Large horizontal components are the reason for large resultant joint moments, especially in the knee joint.

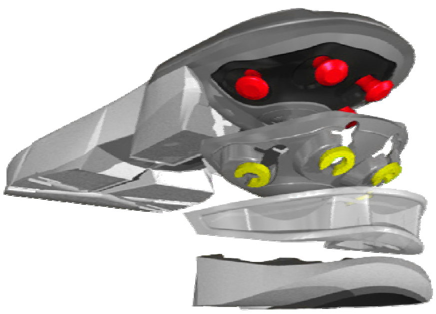

Fig. 4 Illustration of the “Ground Control System”. The illustration shows from top to bottom (a) the top plate, (b) 4 springs, (c) a bottom plate, (d) spacers and (e) clear rubber sealing. With permission of adidas

Research with these Ground Control shoes has shown that the line of action of the ground reaction force during running moved closer to the knee joint axis, reducing, therefore, the resultant knee joint moments substantially. Specifically, tests with 11 subjects showed a significant reduction of the resultant knee moments for external rotation of about 25% compared to the same shoe where the additional horizontal movement was not allowed

(Stefanyshyn et al., 2002). A reduction of the resultant knee joint moments is important because earlier research has shown that the resultant knee joint moments are a strong predictor of knee joint loading and knee joint injuries (Stefanyshyn et al., 2001; Stefanyshyn, 2003). Thus, because of the reduced resultant joint moments, shoes using the concept of the “Ground Control System” are assumed to be advantageous with respect to joint loading and joint injuries in running. Epidemiological studies providing evidence for the assumption of reduced injuries has not been provided yet.
The concept is now used for many different sports (e.g. trail running, hiking, basketball) and applied to the heel as well as to the forefoot.

Individual Suspension Technology
The concept of an individual suspension technology has been proposed by three companies, the Korean company TrekSta with their IST hiking shoes, the Japanese company Asics with their running shoes (Gel Komodo) and Nike with their products summarized by the expression “shox”. All use in principle the same concept. Shoe soles are constructed by using elements that deform independently of each other. Depending on the function, specific suspension elements can be soft (to cushion) or stiff (to provide stability). An individual suspension technology shoe landing on an obstacle (e.g. a rock) will, therefore, tilt less but deform locally. In hiking boots, this system has been shown to reduce shoe eversion substantially (compared to a “normal” hiking boot a reduction of maximal shoe eversion from 21 degrees to 13 degrees). All three producers (TrekSta, Asics and Nike) suggest that the concept of individual or independent suspension has advantages for rear foot control as well as for cushioning.

CUSHIONING
Cushioning is one of the most used functional concepts for sport shoe construction. Almost every sport shoe manufacturer claims to produce shoes that are excellent with respect to cushioning. However, many features in sport shoes that are described as “cushioning” features are more design than function oriented. In addition to this, the paradigm of cushioning has changed in the recent years (Nigg, 1997; Nigg and Wakeling, 2001). Thus, in this section, one shoe design that provides a completely new view of the problem of cushioning is discussed.

Multi Shear System (Asics Gel Helios)
For a long time, cushioning has been treated as a vertical compression problem. However, deformation of the heel of the shoe in heel landing shows often horizontal deformations that are larger than the corresponding vertical deformations. Taking this into account, the Asics engineers made some calculations to determine the construction that is best suited to deal with a multi-shear system. The result of their calculations was a donut shaped structure (Fig. 5).

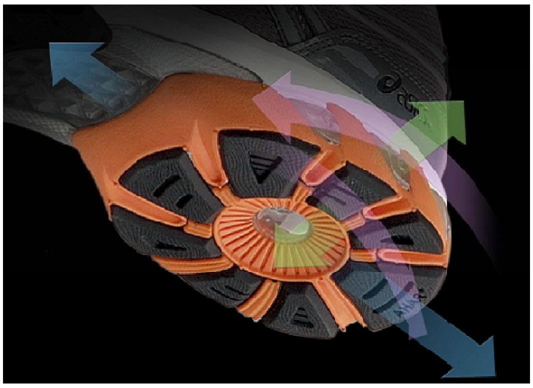

Fig. 5 Illustration of the donut shaped cushioning system developed by Asics (Gel Helios) that takes the amortization of the vertical and the horizontal forces into account

Numerical results of cushioning related quantities are not available to the author. However, conceptionally, the solution seems to be convincing.

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