BIOMECHANICAL EVALUATION OF RUNNING AND SOCCER SHOES: METHODOLOGY AND TESTING PROCEDURES

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Running shoes are the footwear, that has been explored the most by scientists in the field of biomechanics. Following the running shoe research peak between 1980 and 1990 other products became the focus of interest. In particular, many shoe studies were performed in the field of basketball and other indoor sports. Only recently, soccer boots have received a lot of attention and were explored by various research groups. Other than in running shoes, soccer boots have additional tasks to perform. These shoes are used for kicking, they should provide sufficient traction for rapid cutting manoeuvres and assist the players in rapid acceleration and stopping movements. Especially, the often conflicting demands of injury prevention and high performance properties remain to be solved. Test methods for athletic footwear as well as research results will be presented here. This will demonstrate how important biomechanics has become in providing the necessary knowledge for the design of functional footwear.

KEY WORDS: athletic footwear, running shoes, soccer boots

INTRODUCTION:

For most sport disciplines, athletic footwear serves to provide comfort, protect the body from excessive loads, and to improve performance. As an example, reduction of shock and overpronation at the subtalar joint are key factors in avoiding overuse injuries in runners. Appropriate footwear is also needed to stabilize the foot against inversion trauma in many athletic events. Performance aspects are related to the reduction of energy expenditure by sport shoes in endurance sport activities. Good traction and stability properties of footwear may also help to cut and turn faster in team sports (e.g. soccer). Depending on the various sport disciplines, the requirements of athletes are addressed by specialized footwear constructions. In depth knowledge of foot morphology and anatomy, aetiology of commonly reported injuries, and lower extremity mechanics form the basis of footwear creation/engineering.

RUNNING SHOE EVALUATION:

This chapter will describe methods of running shoe testing. Pronation control and shock absorption are considered to be the main concepts for injury prevention in running shoe design. All major running shoe manufacturers follow these concepts.

Material Testing: Impacter devices are widely distributed in the shoe industry to measure midsole properties of running shoes. Typically, a mass of 8.5 kg falls from a height of 5 cm onto the heel area of running shoes. The mass of 8.5 kg shall mimic the effective mass of a runners leg at initial foot contact during running. We compared the impacter data from 19 different running shoes to the shocks that were measured on 27 subjects when they were running in these 19 shoes. Peak accelerations of the impacter tests were compared to the peak tibial accelerations during running. The comparison of the two variables resulted in a determination coefficient of only 7%. Therefore, impacter tests are not able to estimate the impact in running. Biomechanical measurements on the human body have to be performed to evaluate and judge the shock attenuation properties of footwear. However, mechanical impacter devices can be used to determine the homogeneity of materials and shoe constructions between different pairs of shoes of the same shoe type or even within shoe pairs (left-right comparison). Mechanical impacters are well suited to determine production tolerances.

Biomechanical Testing: Rearfoot motion control and shock absorption are the two main criteria for a biomechanical evaluation of running shoes. Additionally, in-shoe pressure distribution information is useful in providing more insight in the effect of footwear on foot loading and foot motion. The plantar pressure distribution information is like a finger imprint. It provides detailed information about individual features of shoes.

Measurement of rearfoot motion: In the past high-speed film or video were used to determine rearfoot motion at ground contact on a treadmill or during overground running. Furthermore, opto-electric techniques with the possibilities of automation and digital processing are used in quantifying rearfoot motion. These analyses are performed by using two markers on the heel counter of the shoe and two markers on the leg below the knee in the direction of the Achilles tendon. Film analyses are time consuming. Alternatively, electronic goniometers can be used to measure rearfoot motion. The main advantage of electronic goniometers is that the results are immediately available. Electronic goniometers are fixed onto the heel counter of the shoe. A lightweight half-circular metal construction with a potentiometer is fixed at the heel counter with its axis of rotation at the approximate height of the subtalar joint. The movable part of the goniometer is fixed at the lower leg in parallel to the Achilles tendon orientation. The advantage of the goniometric method is a fast data acquisition that can be performed simultaneously with the measurements of ground reaction forces, tibial accelerations and pressure distributions. As shown in Table 1, substantial differences in pronation and pronation velocity values do exist in commercially available running shoe models.

Measurement of shock absorption: Force platforms are well suited to estimate the shock, travelling through the body at initial ground contact. A close relationship exists between the vertical GRF rising rate at initial foot contact and the tibial acceleration, as measured by light weight accelerometers at the lower leg of runners (Hennig et al., 1993). The authors studied the influence of footwear on the peak tibial acceleration of 27 runners in 19 different running shoe models. When comparing this maximum force rate with the peak tibial acceleration values in the different shoe conditions a simple regression analysis showed a determination coefficient of 95 % between these two variables. In the same study Hennig et al. also calculated a median power frequency from the Fourier spectrum of the vertical ground reaction force signal. The median power frequency also showed a very high correlation of r=+0.94 with the peak tibial acceleration values from the different shoe models. In conclusion, the following three variables are very well suited to differentiate between the shock absorption properties of footwear in running: peak tibial acceleration (PACC), maximum force rate of the vertical GRF signal, and the median power frequency of the vertical GRF. Table 1 shows substantial differences in peak tibial accelerations values for different running shoe models.

Plantar in-shoe pressures measurements: Force plate measurements only provide information about the total ground reaction force acting on the body. The loading of individual foot structures which may play an important role in the occurrence of overuse injuries can only be determined using pressure distribution devices. Matrix sensor insoles can easily be placed inside shoes. Because most feet exhibit individual anatomical variations, the exact placement of the sensors under the anatomical sites of interest are not known. Furthermore, depending upon shoe construction peculiarities, the relative positioning of the insole matrix under the foot may vary. To overcome these problems, pressure insoles with a high number of small transducers are necessary. However, pressure insoles with a high density of accurate sensors are expensive. They generate many data but have restricted time resolution. The use of a limited number of discrete rigid transducers offers an alternative for gathering in-shoe pressure information. They are typically fixed with adhesive tape under palpated anatomical foot structures that are manually palpated. The major advantage of this technique is an exact positioning of the sensors under the foot structures of interest, independent of individual foot shape. It also guarantees that the sensor locations remain independent from footwear construction peculiarities. As shown in Table 1, substantial differences in peak pressure values do exist in commercially available running shoe models.

Table 1 Results from 20 subjects running in 15 running shoe models

Shoe	P-ACC (g)	PRON (°)	PVEL (°/s)	PP-H (kPa)	PP-M (kPa)	PP-F (kPa)
A	5.9	8.7	391	844	247	509
B	5.7	11.1	451	668	367	498
C	4.7	10.0	660	691	334	475
D	6.4	10.9	466	775	381	489
E	7.5	10.0	478	849	266	513
F	6.6	9.8	614	734	347	526
G	6.1	10.7	539	803	326	576
H	7.9	8.3	580	879	306	574
I	6.4	11.7	480	793	291	534
J	6.4	10.8	571	729	231	497
K	6.7	10.7	537	709	289	504
L	5.0	10.2	578	848	346	600
M	6.5	10.1	673	791	319	595
N	6.6	9.6	554	750	292	588
O	6.2	8.8	515	691	273	496

Variables: Peak tibial acceleration (P-ACC) , maximum pronation (PRON), maximum pronation velocity (PVEL), maximum pressures under the heel (PP-H), midfoot (PP-M) and forefoot (PP-F)

Subjective Shoe Evaluation: Some shoe features are difficult or impossible to measure by technical or biomechanical instrumentation. The fit of a shoe, comfort and foot climate are some of the criteria that will have to be answered by the runners. It is also important whether the runners will experience pressure sores or blisters during running. In our running shoe tests we typically have about 20 runners who run a distance of 10 km in each of the shoe constructions on different days. Assignment of the shoes is randomized and the runners fill out a questionnaire at the end of the run. Using a 15 point perception scale the runners will answer questions on the following items. How is your overall liking of the shoe and how do you rate shock absorption, pronation control, fit, handling of the shoe, traction properties, and foot climate. A separate section is included in the questionnaire where subjects report on the occurrence of pressure sores and blisters and at which location of the shoe they occurred. At the end of the field test we have ratings and comments from all runners for each of the shoes. Depending on the number of tested shoes, the field test period will have a duration of 6 to 8 weeks.

In conclusion, only the combination of biomechanical data, subjective evaluations from a field study, and material test results provide the necessary information for a good running shoe survey.

SOCCER SHOE RESEARCH:

In spite of the world wide popularity of soccer, much less research has been published about soccer shoes when compared to running shoes. As compared to well established evaluation criteria for running shoes, soccer shoes have to fulfil many more game related demands. According to a survey that was carried out in our laboratory, there is primarily the need for comfort, traction and stability. In the following sections some of the - sometimes surprising - results will be presented.

Recognition of Movement Patterns - Game Analyses: Tracking of soccer players with GPS provides the possibility of recording the total distance covered by players during the 90 minutes of the game. In recent years soccer has become much more dynamic and players cover distances of more than 12 km. GPS tracking also allows to analyze the speed patterns of different players. Our analyses showed that the outside as well as the midfield players cover the longest distances during a game and achieve the highest running speeds. Video game analysis of the last two world championships of the men and the last world championship of the women also gave us an insight into the modern game of soccer. Differentiated with regard to player category we analyzed all ball contacts of the players with regard to kind and frequency and where in the field they occurred. Of special interest was the specific location of the shoe that made contact with the ball during the different kicks in the field and on the goal. Differences between the soccer play of men and women were also analyzed. This information is important for construction features of the shoe construction.

Evaluation of Comfort: Fit and comfort are the most important features that soccer players expect from their shoes. The pressures under the foot are closely related to the perception of comfort. Therefore, pressure distribution insoles are well suited to evaluate comfort properties in soccer shoes. Placement of the cleats and studs, outsole construction and shoe plate stiffness influence the pressures under the foot. Therefore, pressure distribution measurements are a good method to evaluate comfort properties of the shoes.

Traction and Stability Properties: Playing soccer requires players to perform many types of movements at all speed levels. Especially, for movements at high speed levels traction is one of the most important shoe feature for successful performance. Traction, after comfort, was marked second among the most important soccer shoe features according to a players' survey on soccer shoe properties. The idea of a functional traction test (FTC) is that traction properties have an immediate influence on running time. Unsuited traction properties of a soccer shoe may result in stumbling or slipping causing thus causing longer running times for a given parcours. A FTC parcours should incorporate sections with multiple acceleration, deceleration, cutting and turning movements. From multiple FTC studies, carried out at our laboratory, we found significant differences in running times for stud type, stud geometry and stud length on the same parcours at a given weather condition. Low shoe weight also had a positive effect to achieve better running times. Of course, the type of grass surface and weather condition also had major effects on the results of our FTC for different shoe constructions.

Kicking Speed: Soccer shoe construction has an influence on maximum kicking speed during full instep kicks. Although the gain in maximum speed by a better shoe is only in the order of 2 %, it may still decide on the few centimetres that the goal keeper would need, to reaches the ball with his hands. Sterzing and Hennig (2008) performed a number of experiments to investigate soccer shoe properties on kicking speed. A surprising finding in these studies was the fact that soccer players achieve higher maximum kicking velocities with their bare feet. During barefoot kicking the players have a higher degree of foot plantarflexion which allows a better mechanical coupling of the foot to the shin. Thus, a higher effective mass creates a larger impulse of the impacting lower leg. This results in a higher kicking speed. Kicking speed can be determined by photo cell arrangements or more efficiently with radar guns.

Kicking Accuracy: Not many soccer players would believe that a shoe can influence kicking accuracy. However, we found significant ($p < 0.01$) differences in kicking precision when subjects had to hit a target with different soccer shoe models using the same kicking technique. Other than for the maximum kicking speed, barefoot kicks had lower accuracies ($p < 0.01$) in comparison to all shoe conditions (Figure 1). Shoe-C also showed significantly ($p < 0.05$) better accuracies when compared to all other shoe models.

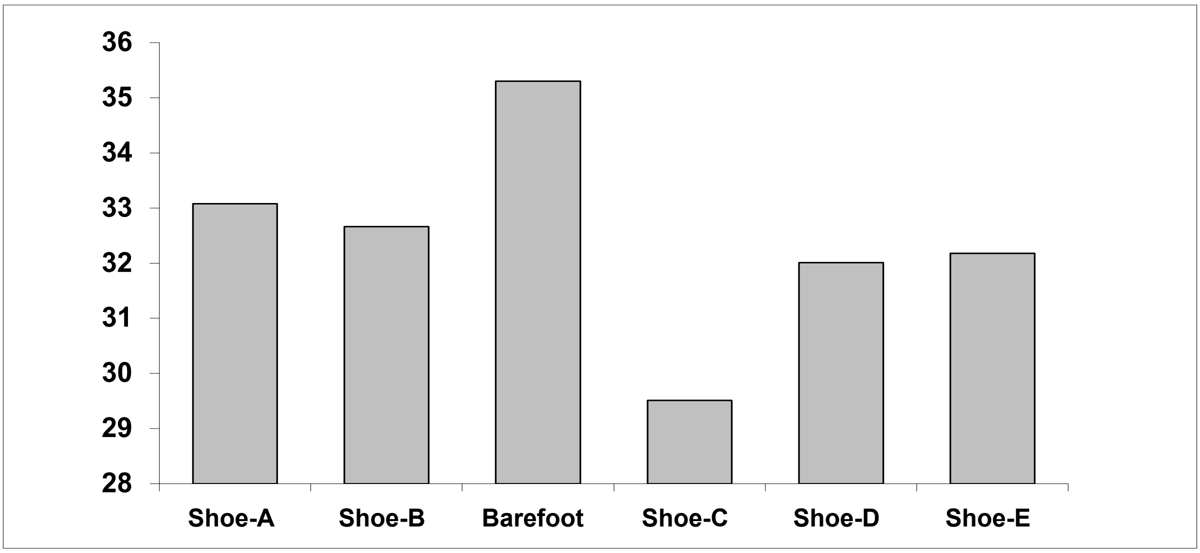

Figure 1: Kicking accuracy for instep kicks in different shoes and barefoot

From multiple studies on kicking accuracy we concluded that avoiding high pressure gradients across the foot during ball contacts improves kicking precision. Apparently, the bony prominences of the bare foot prevent an even pressure distribution across the contact area of the ball with the foot. The shoe upper material distributes the high local pressures by the bony prominences across a larger area and thus reduces pressure gradient values to adjacent areas.

CONCLUSION:

Biomechanical measurements provide valuable information about the properties of athletic footwear. For running shoes the risk of overuse injuries has been the focus of research for many years. Overpronation and a lack of shock absorption properties have been linked to the occurrence of many overuse injuries in the foot, knee and hip regions. Therefore, these variables are of major interest for running shoe testing. A combination of biomechanical data, subjective evaluations from field studies, and material test results provide the necessary information for good running shoe tests. To evaluate the quality of soccer shoes is much more complex and tests are more difficult to perform. Soccer shoes are used for kicking, they should provide sufficient traction for rapid cutting manoeuvres, and assist the players in rapid acceleration and stopping movements. Biomechanical research did show that running performance, quickness of the players on the field, kicking speed, and kicking accuracy can be influenced by shoe design. To combine these performance aspects without compromising injury prevention features are a major challenge for soccer shoe design in the future.

REFERENCES:

Hennig, E. M., Milani, T. L., & Lafortune, M. A. (1993). Use of ground reaction force parameters in predicting peak tibial accelerations in running. Journal Applied Biomechanics, 9(4), 306-314.
Hennig, E. M., & Milani, T. L. (2000). Pressure distribution measurements for evaluation of running shoe properties. Sportverletz Sportschaden, 14(3), 90-97.
Sterzing, T., & Hennig, E. M. (2008). The influence of soccer shoes on kicking velocity in full-instep kicks. Exerc Sport Sci Rev, 36(2), 91-97.

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