METHODOLOGICAL APPROACH IN DESIGNING SPORT SHOES

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INTRODUCTION

This paper try to focus its attention to two major topics related to the design of sport shoes. It will be described the basic aspects that must be considered when the designing of sport shoes is faced by means of a multidisciplinary approach in which biomechanics play an important role, and also some examples of results obtained by researchers who studied the shoe by considering common or specific demands, arising from various sports will be repurted.

Sport activity is an ensemble of motor actions which requires different kinds of physical effort and also implies different physiological mechanisms and biomechanical patterns. Some sports are characterized by maximal actions expressed in a short time period and repeated some or many times after a recovery. Other sports imply a submaximal effort performed with continuity for a long period of time without recovery. Finally there are sports in which there is a combination of the previous two situations.

By considering sport activity from a biomechanical point of view, it is not possible to forget that the movement of the body arises because of the dynamical equilibrium of the external forces and moments. The equilibrium is reached through interactions between athlete and environment and, eventually, bctween athlete and opponent. Of course the interaction between athlete and environment depends on the kind of sport. More frequently, it occurs between the foot and the playing surface. In other words foot and lower limb are devoted to sustain a wide range of mechanical loads depending on the movement.

Since the athletes are affected by pathologies of the lower limbs (Clement et al., 1984) and the spine, the mechanical loads may be reasonably identified as one of the most consistent source of injury. This relationship is certainly amplified by other factors: the technical evolution of the sports, the increase of time devoted to training and number of competitions, changes in playing tactics like pressing and zone defensive making in soccer. Therefore also the sport shoe, which represents the sole interface between foot and playing surface, must answer to this new functional requirements with solutions aimed to modify and reduce at best the loads without decreasing the efficiency of the motor performance.

The complex task to identify all the variables which influence the foot-ground interaction and the finding of useful solutions may be successfully faced by means of applied researches based upon a multi-disciplinary approach.

The most important fields of analysis may be resumed as follows:

- the athlete to detect the most important body's characteristics of each population of sportsmen and to know the problems they have with the shoe;
- the snort to identify basic movements determining the performance and to evaluate the potential influence they have on the loads production for the muscolo-skeletralpparatus with specific

- the biomechanics to quantify in an objective way through measurements and mathematical models, the kinematics, the kinetics and to estimate the muscolo-skeletral loads. Then on this basis to verify the influence of the shoe-surface interaction on the movement;
- the materials to propose new solutions able to match the identified needs and to verify the maintenance of the mechanical characteristics during the use.

METHODS AND RESULTS

Athlete

The primary need to the subject of the sport activity is to set up a data bank of the anatomo-physiological characteristics of athletes who practice different sports. In this frame it is fundamental the availability of groups of subjects practising the sport with continuity and at a representative level. For this specific purpose, in our cxpericnce, two groups of approximately twelve-fifteen athletes per sport have been recognised as a reasonable sample of each population.
Usually the first group is composed by athletes ranked in the first places of the world or national lists. These athletes have a wide experience and are familiar with every detail (shoe included) to improve the performance. The second group is a team or a group of athletes ranked at regional level that may be more easily involved in tests and experiments.
Data collection of the lower limbs characteristics is based on two main approaches: the epidemiological and the experimental one.

The epidemiological approach is performed by means of a protocol designed for an anthropometric inspection of the athletes.
The protocol includes: clinical inspection of orthopaedic specialist, photo records of the foot and lower limbs, foot print of the plantar surface, measurement of geometric data of the foot that are important for the construction of the shoe: instep and instep girth.

Basically clinical inspection, integrated with photo records, is utilized to identify paramorphysms or pathologies that can influence the opinion of the athlete on the shoe.
Foot prints are digitized by means of a computer interfaced device in order to speed up and simplify the measurement of standard clinical parameters. A specific software allows to collect and store the data and perform some basic statistics.
In table 1 are reported examples of data measured on a population of forty two football players.
Foot shape, toes formula and rear foot axis show that the group do not differ from a population of normal males, even if the flat foot is present with a percentage lower than in the normal population.
It is interesting to note the small differences among the values of instep (249.5 mm., sd=9.5) and instep girth (268.0 mm., sd=10.7) are in agreement with the players' request of close-fitting and slender shoes than other kind of sport shoes.

Literature (Daum B., 1987), clinical records and data arising from the questionnaires distributed to the athletes point out some specific problems of the functional unit foot-shoe.
The most common problems are mainly dependent on chronic pressures of the foot. The anatomical areas interested may be listed as follows:
- distal insertion of the Achille's tendon,
- first metatarsal-phalangeal joint (PIP) on the medial side;

- dorsal area of the proximal inter phalangcal articulations;
- nails (subungual hematoma),
- blisters of toes, heel and plantar surface.

FOOT SHAPE

Cavus	Normal	Flat
19.0 %	76.2 %	4.8 %

TOES **FORMULA**

1th>2nd	1th=2nd	1th<2nd
12.1 %	39.2 %	48.7 %

REAR-FOOT **AXIS**

Varus	Neutral	valgus
29.8 %	65.5 %	4.7 %

TABLE I Foot parameters of a population of 25 professional football players.

In order to reduce the causes producing hyperpressures it has been faced the problem of chronic pressures on the dorsal area of Proximal Interphalangeal joints (PIP) that is very often reported by athletes and players.

It has been carried out a research to measure the distance of the PIP of each toe from the support plane, according to different postures (Rodano R. and Vigano' R., 1991).

The data concerning to the tri-dimensional coordinates of PIP have been measured by means of an optoelectonic motion analyser, the ELITE System (Ferrigno G. and Pedotti A., 1985), which uses passive retro reflective markers to identify the choosen anatomical points.

The system utilizes hardware implemented algorithms of computer vision in order to recognise on line the luminous areas on the TV images, corresponding to the markers ligthened by infrared flashes.

An highly automatised procedure of tracking attributes the correct anatomical assignment to each marker, whereas the solution of stereophotogrammetric equations allows for the computing o i the spatial coordinates. All these prucedures are performed by a proper software, implemented on personal Computer.

The size of markers is strictly dependent on the size of the field of view and in this survey the markers had a diameter of 3 mm and the accuracy of the measurements was 0.1 mm.

During the experiments twenty five long distance runners were asked to stand in diiferent positions:

- bipodalic,
- monopodalic,
- bipodalic on the tip of the toes,

- monopodalic on the tip of the toes,
- simulation of the step push-off.

The results show that the vertical shift is comparatively bigger in the PIP of the second toe in a condition of monopodalic standing.

Sccond. third and fourth toe show an increase of height when the postures are on the tip as consequence of the prevalence of the extensor muscles on the flexors. The first toe associates a decrease in height when the support becomes monopodalic and the equilibrating function of the toe becomes crucial. During the step's push-off simulation all the PIP decrease their height as consequence of the flattening due to the flexing action of the muscles that act to fix the toes on the ground.

In order to deepen the relationships between foot and shoe, which can be crucial in the forefoot area, X ray and CT (Computerized Tomography) examination have been utilized. The tests have been performed by voluntary subjects both barefoot and with shoes on. X ray records have been applied to assess the position of football boots' cleats by respecting the functional needs of the foot. CT records have been used to quantify the deformation to which the foot is subjected when different kinds of shoes are worn. Sections of the CT records made at different levels on the foot, allow after the identification of the anatomical landmarks, measurements along the line of the toes and along the line of the metatarsal heads.

The results point out:

- the small amount of compression of the forefoot
- the significative compression of the toes
- the change in axes orientation of the toes (lateral for first and second toe, medial for the last three toes).

Sport

The second frame of the approach is aimed to the knowledge of those aspects of the sport that strictly involve the function of the shoe.

Many authors studied different sports by means of the analysis of film or TV records in order to define, in terms of time duration and frequency of occurrence, specific events characterizing the varius motor activities.

By considering running activities, Kerr et al. (1983) report that the percentage of heel striker runners increases when the velocity decreases from 45% at 340 m/min to 80% at *205* m/min. Moreover they indicate that during long distance races the percentage of heel strikers is almost constant (80%). These lindings suggest to design running shoes that must take into account this two populations and their biomechanical needs.

Soccer is an activity where many different movements are performed by the players. Lees and Kewley (1991) quantify the percentage of occurrence for ten basic playing actions in condition of professional training, professional play and immaterial play. Source of the data were TV records of the play. An interesting indication arising from the results is the large reduction of occurrence of turns (-13.3%) and jumps (-9.3%) when the professionist play in comparison when they are training. These findings, by considering the role of the shoe during these movements, may suggest the use of shoes with different characteristics of the sole. Rodano et al. (1988) report similar results obtained by means of a special TV set up and image processing. In this study the

authors were also aimed to observe and classify the dynamical behaviour of the lower limb and the foot during the play to set up protocol of biomechanical tests.

An other example of study of sport characteristics is given by Gallozzi and Colli (1992) who processed TV records of top level tennis players during competitions. The authors computed many variables as: rest time duration, set time duration, playing and recovery time duration. The data allow a comparison between male and female characteristics of play in function of the surface. On the average men play for a shorter time than women. The time depends for all on the surface, becoming shorter when playing on the grass and longer on clay. The results, considered together with the difference of movements' velocity and body mass between men and women, suggest a differentiation of design between the shoes used by each group.

Biomechanics

The third field of interest for designing a sport shoe at best is biomechanics. In other words the knowledge of quantities concerning kinematics, dynamics (external forces like ground reaction forces and moments, internal forces and moments like joints reactions and joint moments) pressure distribution between foot and sole of the shoe.

Some common problems have been deeply studied by biomechanicists:

- control of rearfoot movements,
- cushoning properties of the shoe,
- friction properties of the shoe-ground system.

The influence of the shoe on the physiological movement of prono-supination of the foot during the support phase of running has been analyzed because some relationships have been recognized between excessive pronation and injury (Clement, 1981). Measurement of calcaneal eversion is considered as indicator of pronation. The most common technique adopted to measure this variable consists in evidencing, by means of four markers, the two imaginary lines that define leg and rearfoot. Once the markers' coordinates are measured, by means of film digitation or by optoelectonic systems, it is possible to compute the geometric parameters of the lines in the frontal plane, the angles that they form with the vertical and between them. Derivative computations give the rate of the angles' variation. It has been demonstrated that the shoe produce appreciable changes in rearfoot movement in comparison with barefoot running (Nigg et al. 1981). Shape of the heel sole together with the combination of materials of various density influence many factors of this movement as: the angle between foot and ground, the angle between foot and leg, and the angle between leg and ground (Nigg 1986).

An influence of the shoe construction on the lower limbs kinematics has been demonstrated by Luethi and Nigg (1985) who examined a population of tennis players who performed lateral movements with different kind of shoes (soft and hard sole). The author conclusions evidence, once again, the influence of the shoe construction on the kinematics of the lower limb and the relationship between fast lateral movements and arising of pains and injuries.

Recently an optoelectonic system has been utilized to measure simultaneously the X-Y-Z coordinates of markers placed on cyclists to evaluate the action of pedalling (Rodano and Vigano', 1992 a). The application of the protocol, aimed to quantify the influence on the kinematics of the lower limb of the shoe design and the kind of device used to fix it to the pedal (Rodano and Vigano', 1992 b), points out that hip and knee angles do not modify time course and

range of variation contrarily to the joints markers. This finding seems to support the idea that the cyclists try to adjust the kinematics of the lower limb in order to find in every condition, the most convenient range of motion of the propulsive muscles. On the other hand trajectories of the foot and ankle angles are significatively dependent on the condition. Moreover the new generation of pedals, that provide a firm link between foot and bicycle, guarantee a lower variability of the kinematic parameters.

Sport activities involve repeated impact of the foot on the ground and the loading transmitted to the body may be recognized as cause of many pathologies of the lower limbs. An index of the interactions is represented by the ground reaction force that guarantees the dynamic balance during the support phase. The ground reaction force, usually measured by means of force plates, is dependent on body mass, sport activity, speed of the movement, lower limb and foot kinematics and surface (Nigg, 1986; Tiegermann, 1983).

When running is considered it has been evidenced that the shoes have no significative effect on contact time and magnitude of the ground reaction peaks. Otherwise soft shoes produce a delay of the impact peace (Nigg, 1985). The lack of differences may be caused by modifications of the motor patterns, through which the athlete try to adapt his characteristics to different cushioning systems.

Anyway sole hardness and thickness have significative effects on reducing the loads transmitted to the body (peak deceleration of the leg and peak plantar pressure). Then it is possible to conclude that in sport shoe design the values of this quantities represent a typical problem of optimization as soft and high soles reduce peak loads but cause foot instability and modify the motor coordination of the athlete.

Looking at football boob, Lees (1991) made a significative attempt to relate ground reaction force and shoe demands in typical movements of the play by means of a severity index (total impulse divided by support time duration). He observed that turn, run, jump and start are the action during which the stress is highest. Furthermore during the first three actions it is due primarily to horizontal forces.

Ground reaction forces and kinematic records have been also utilized to design devices able to simulate actual movements (Rodano, 1983) and then to compare the cushoning properties of the shoes under strictly controlled conditions.

A new generation of measurement devices, based on thin insoles containing a matrix of more than a thousand transducers, is available to measure the pressure distribution between the plantar surface of the foot and the sole. The knowledge of this quantity is very important both for biomechanicists and for podologists in order to avoid the causes of hyperpressures. This result may be reached through the design of the sole and/or the use of specific orthotics (Boccardi et al., 1992).

Materials

The last step of sport shoe design is the choice of the materials to use. Many tests, following international standard like abrasion, compression and fatigue tests are carried on the materials by the shoe makers. Otherwise it is important to obtain information concerning the behaviour of the material when is subjected to loads that can simulate actual condition of use.

Usually the shock-attenuating properties of the materials are compared with impact tests designed

to measure the force-time, the deflection-time and the energy return properties. Some different dcviccs have been developed for the purpose:

- impact head which is dropped on a sample of cushioning material. Force, velocity and displacement transducers allow to compare characteristics of the impact;
- sphere of steel which is dropped on samples of the material leaned on a load cell. Force and time of rebound are the variables measured;
- artificial foot, linked with the ann of a pendulum which is dropped on a force plate to simulate rearfoot and forefoot impacts.

Other tests have been proposed by researchers to measure the traction due to the type shoe-surface interaction, as excessive traction of the sole (Torg and Quedenfeld, 1974) or of the surface (Morehouse and Morrison, 1975) have been often implicated in many injuries . The studies involve tennis shoes (Schlaepfer, 1983), basketball shoes (Vailant, 1987) and football shoes (Van Gheluwe et al., 1983; Vailant, 1988).

CONCLUSIONS

The general indications arising from the study of the sport shoe problematics suggest that a multidisciplinary approach to the problem is almost mandatory and it involves athlete, sport, biomechanics and materials.

By considering the functional unit foot-shoe, shoe makers must try to design shoes able to avoid hyperpressures and ensure good fit. Shoe shaped by considering the common anatomical characteristics of each population of athletes and the deformation produced on the foot when the shoe is worn, seems to be appropriate to perform these tasks.

Biomechanical aspects together with mechanical characteristics of the materials, must be analyzed carefully. We must remember that each reasonable solution proposed to decrease the muscolo-skeletral loads and aimed to avoid physical damages, modify the motor coordination of the athlete. To predict the long term influence of this modification is almost impossible. Then a multifactorial analysis of the influence of the shoe on the movement is desirable.

In conclusion it is possible to state that designing a sport shoe is a very complex task in relation with the large amount of need arising from the differences recognized among sports, athlctes and playing surfaces.

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