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The role of research in the creation of athletic footwear

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ABSTRACT

Athletic products must meet the needs of athletes and the demands imposed by sports through innovative design. These needs of athletes and requirements of sports are performance, protection and comfort related. In depth knowledge of anatomy and physiology, etiology of commonly reported injuries, and lower extremity mechanics form the basis of product creation/engineering. Game analysis which entails time and frequency surveys of the skills performed during a game, interviews with athletes and coaches, and discussions with medical staffs are used to identify the skills that are critical to the needs of athletes. In lab full biomechanical analyses of these skills and/or physiological responses of the athletes lead to clear functional criterions that serve as guidelines to be met by the design team. The concepts created by the design team are in turns subjected to the same battery of biomechanical analyses. The learning gathered through this pluridisciplinary process is used to further evolve design concepts. The evolution-testing loop is repeated until biomechanical and/or physiological, mechanical and perceptual tests indicate that the design concept meets the established functional design criterions. At that time, the design concept is ready for manufacturing research and development. Additional biomechanical and physical tests are performed through that phase to confirm that the manufacturing processes preserve the functionality of the design concept. Durability and long term performance of production samples are evaluated through a final three month long weartest program. A rigorous research/testing program is crucial to create and engineer sport products that meet the performance, protection.

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INTRODUCTION

Authentic athletic footwear must meet the needs of athletes and the demands imposed by sports through innovative design. These needs of the athletes and demands of the sporting activity are performance, protection and comfort related. They depend upon sport, gender, age, skill level, regional sport culture and physical environments such as playing surfaces and climates. From the athlete perspective, the differentiation between injury protection, comfort and performance is often blurred. Yet, it is known that injuries can reduce ones performance, prevent him/her from playing/training and even leave sequels that will limit future performance and ultimately affect daily living activities. Similarly, discomfort may get in the way of ultimate performance through distracting the athlete from the task at hand. Individual preferences play an important role in an athlete footwear, apparel and equipment choice. Materials and structures are ingredients of products responsible for providing functional features such as cushioning, stability, support and protection against the environment. Thus, a comprehensive approach that comprises biomechanical, mechanical and sensory/perceptual evaluations is required to create and develop innovative athletic footwear that meet the needs of athletes around the world.

ATHLETE NEEDS AND ACTIVITY DEMANDS

The first phase in the creation of athletic footwear involves the identification of the needs of the athletes who will use this particular shoe model. Injury surveys, game analysis, discussions with team medical professionals, coaches, athletes and sport scientists are important sources of information used to identify the needs of athletes. They also provide information about the specific demands imposed onto the athletes by the sport. Since each footwear model targets a specific group of athletes, the research must focus on individuals who are representative of the target population.

Retrospective injury surveys compiled incidence, types and frequencies by types of injuries from clinic or team records. Prospective injury surveys add denominator based data to more accurately assess injury parameters including incidence, anatomic location, diagnoses, and most importantly associated causative factors. Injury trends for running are welcome having been the topic of several surveys (James et al., 1978; Clement et al., 1981; Marti et al., 1988; Van Mechelen, 1992). The injury trends in other sports are less known. Until recently, there was no injury

survey of injury of young soccer players. The data from the Coach K Human Performance Laboratory (Duke University Medical Center, 2000) show clear injury trend differences between young and collegiate athletes (Table 1). The data also indicates that girls are injured 1.5 times more often than boys.

Table 1. Distribution of lower extremity injuries by lower extremity anatomical locations in young and collegiate soccer players

Anatomical Locations	YOUTH	NCAA*
Ankle	38%	31%
Knee	29%	26%
Lower Leg	12%	10%
Upper Leg	11%	23%
Foot	14%	10%

*Adapted from the NCAA ISS 1995-1996 report.

Game analysis provides frequency and temporal inventories of the skills/maneuvers that are performed during games or training sessions. Skills/maneuvers that make up the game are catalogued and observers are trained in identifying their occurrence. Game analysis can be performed during actual games or through visioning previously recorded matches. Post-processing of the data may involve grouping the information by player position, gender, time in the match, first versus second half, or other relevant categories. For instance, through game analysis, it is possible to find out how different the game of basketball can be depending upon player position on the court and gender (Figure 1).

Follow up discussions with medical professionals help identify the skills/maneuvers that are most commonly associated with injury. The etiology of commonly reported injuries is critical to design footwear that will protect the athlete. Discussions with coaches and athletes are used to identify the skills/maneuvers critical to athletic performance. Feedback on current product is also sought through surveys and informal conversations with athletes. Combined with the results of injury surveys, this information allows for the identification critical skills.

BIOMECHANICAL RESEARCH

The second phase in the product creation process involved an in depth biomechanical analysis of the critical skills/maneuvers. The analysis focuses on the mechanics of the lower extremity, the

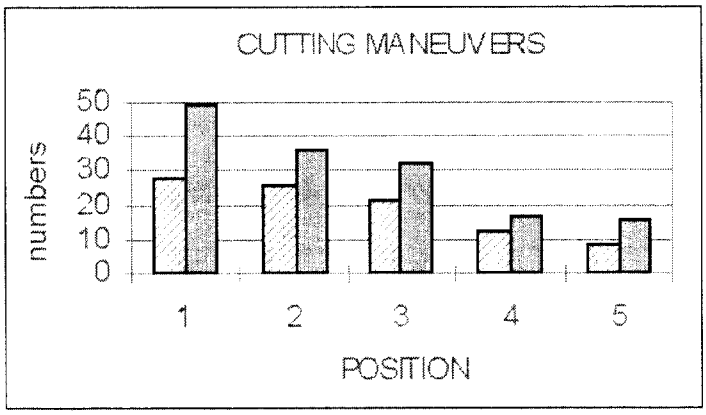

Figure 1. Number of cutting maneuvers performed by basketball players. Position 1 refers to the guard while position 5 refers to the center. Men are represented by solid bars and women by patterned bars.

interaction between ground/shoe and athlete, and the dynamic response of the locomotor system during the execution of the critical skills/maneuvers. Foot morphology is an additional research focus of the as it plays a vital role in the fit of footwear.

Measurements of the forces that underlie the movement of the body during sporting activities provide a direct estimate of the loads to which the athlete body is subjected when the foot interacts with the ground. Force platforms, pressure sensors and accelerometers are used to characterize these loads. The variables derived from these three measuring tools are closely related. The interaction of the foot with the ground generates a reaction force from the ground that is applied to the foot. This reaction force is distributed under the plantar surface of the foot and its effect is to accelerate individual body segments and transmit force.

Ground reaction forces, plantar pressure profiles and tibial shock variables define the cushioning attributes that the footwear must provide. While ground reaction force and tibial shock provide the general characteristics of the footwear cushioning system, plantar pressure mapping adds a detailed breakdown of the load carried by the individual structures of the foot. Thus, pressure mapping allows for regional tailoring of cushioning system. In a sport as soccer, plantar pressure information is critical to develop cushioning solutions that address the high discrete loads associated with the position of the studs under the boot (Figure 2). The shear component of ground reaction quantifies the traction required to perform the activity. Local tailoring of outsole traction is obtained by shear ground reaction force with the plantar pressure mapping.

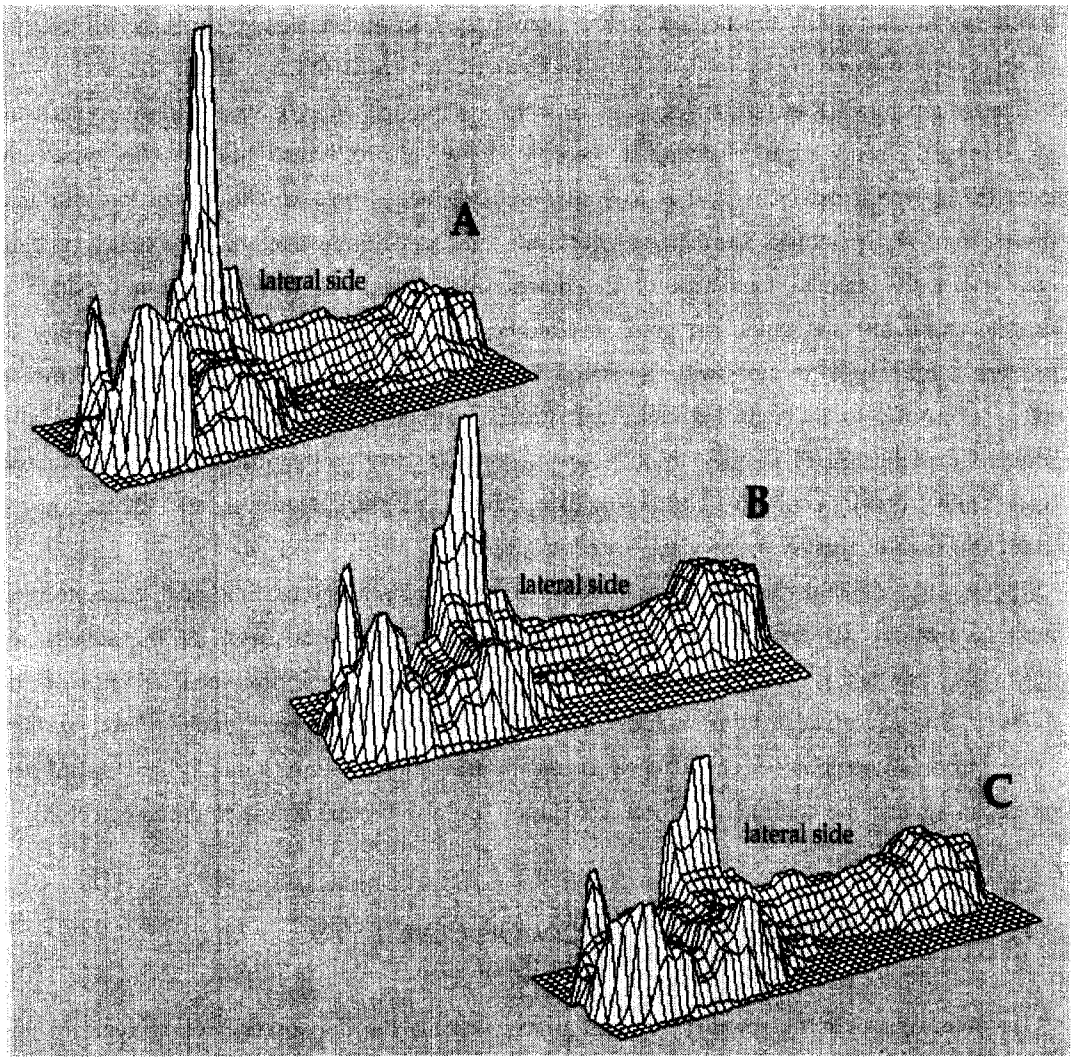

Figure 2. Peak plantar pressure profiles for soccer cutting maneuvers. A) Traditional plate with detachable studs, B) Pebax plate with ridges and integrated studs, C) Same as B with the plate cupping the underfoot.

Three dimensional motion analysis systems that characterize the kinematics of the lower extremity allow for a direct assessment of the stability and support needed by the foot and ankle during the execution of athletic skill/maneuvers. Stability and support in the context of footwear refers to the ability of the shoe to resist excessive or unwanted motions of the foot or motion between different structures of the foot. For example, excessive pronation of the foot is believed to be responsible for

more than 50 percent of all running injuries. Ankle stability is critical in all sporting activities that involve rapid changes of direction or landing from jumps. Ankle inversion sprain is the number one cause of injury in soccer, tennis, basketball and other court sports (NCAA, 1996).

Information about foot morphology can be obtained through direct manual measurements with tapes, measurements from photographic records or with sophisticated scanners. Independently from the approach used, the goal is to gather the information necessary to design footwear that fits the foot of the athlete. Current manufacturing practices require that the shoe upper be built onto a last that mimics the shape of the human foot. Thus, the morphological information is used to create last and guide last grading. Grading refers to the allometric scaling of the last to produce a full range of shoe sizes. As stated in previous sections of this paper, the information must be specific to the intended consumer. Recent morphological data collected in Japan have revealed that the feet of Japanese runners are wider, and have shorter instep and lower malleoli than North American runner (Digital Human Laboratory, 2002). However, the differences are much less than suggested by previous anecdotal reports.

The results of biomechanical analyses lead to the establishment of functional criterions that must be met by the design team. The criterions are specific to the needs of the athletes for whom the product is been developed and they relate only to the functional features of the footwear. The functional features include fit, cushioning, stability, support, flexibility and traction. Other functional attributes such as footwear microclimate (temperature, humidity and sweat) and protection against the environment (heat, cold, rain) are also communicated to the design team.

PLURI-DISCIPLINARY EVALUATION OF CONCEPTS

The third phase in the product creation process entails the development of concepts by the design team and the biomechanical evaluation of the functional features of these concepts. Mechanical and field testing evaluation supplement the concept evaluation process. Several physical properties uniquely define athletic footwear. Mechanical tests are used to reliably and validly characterize footwear construction materials, components and structures. Besides being used to fingerprint materials, components and structures, mechanical tests serve to document their durability and resistance to repeated used. They are also used to establish manufacturing tolerances. Special mechanical tests have been developed to characterize the functional attributes of entire shoes. Tests exist to evaluate cushioning, traction, stability, forefoot flexibility,

longitudinal torsion stiffness, water proofness and breathability of athletic footwear. These tests have been created to replicate how athletes used their shoes and their acceptable ranges of output values are based on biomechanical data.

Field testing refers to sensory/perception evaluation of footwear functional attributes. Sensory/perception evaluation requires individuals to rate the sensations aroused by the physical stimuli caused by footwear attributes, athletes are used as measuring instruments (Meilgaard et al., 1991). Intensity rating of functional features aims at quantifying the magnitude of the sensations caused by the footwear. Affective rating provides information about the athlete preference and liking of the attributes. Usability information is obtained by having athletes use product concepts for their intended purpose and comment on their ease of usage.

Field testing of footwear involves the intensity and affective ratings of the following product attributes: cushioning, traction, forefoot flexibility, stability, support, fit and overall performance. Two types of field tests are conducted during the concept evaluation phase. One type of test attempts to mimic the point of purchase (POP) experience. The other type of test (Dynamic Testing) involves actual participation in sporting activities. The POP test focuses on fit construction elements while the Dynamics test focuses on the other footwear functional attributes.

The learning gathered through the biomechanical, mechanical and sensory/perception evaluations is used to further evolve design concepts. The concepts are stripped from features that do not work and new design elements are added to improve performance. The evolution-testing loop is repeated until biomechanical, mechanical and perceptual tests indicate that the design concept meets the functional design criterions established through biomechanical research. This phase of the product creation process lasts between 8 and 12 months. Generally, it involves between 2 and 4 iterations of the original concept.

ADDITIONAL EVALUATION

Following the completion of the previous evaluation phase, the design concept is ready for manufacturing and production. Biomechanical and mechanical tests are performed on an as needed basis to confirm that the modifications necessitated for effective manufacturing are preserving the functional features of the shoe. Sensory/perception test are regularly performed through that phase to insure that proper fit is achieved for the entire size range.

The final production evaluation culminates by a long term wear testing of production samples.

The purpose of this long term wear test is to confirm the durability of the footwear itself and the durability of its functional features through extended periods of usage. Shoes are distributed among a representative sample of the intended consumers. These athletes subject their footwear to intensive use during a period of three months. At the end of that period, they provide feedback on the performance of the shoes. The shoes are returned to NIKE where they are examined for any sign of early failure or excessive wear. If no problem is uncovered, the green light is given to full production of the new shoe.

CONCLUSION

Research plays a crucial role in the creation and engineering of innovative athletic products. To be effective, it must focus on the athletes and the demands imposed by the sport for which the shoe is created. Knowledge of anatomy and lower extremity mechanics coupled with in depth biomechanical understanding of the sport, its participants and their injuries lead to clear design criterions. A holistic evaluation program that includes biomechanical, sensory/perception and mechanical testing insures that new footwear meet the performance, protection and comfort needs of all athletes.

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