29 Athletic Footwear Research by Industry and Academia

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CONTENTS

Athletic footwear research and testing is carried out at industrial and academic institutions with mutual interaction steadily increasing. This chapter illustrates the circumstances and interaction opportunities of the two settings from an industrial perspective. It describes how fruitful interaction can be organized by discussing respective structural characteristics. The continuous demand of functional and commercial footwear innovation serves as background for the introduction of the standard product creation process. Additionally, the important preceding role of academic baseline research to establish solid proof of innovative and functional footwear concepts is described. The key company departments involved in the product creation process, planning, design, and development are introduced by illustrating their respective roles during product creation. Thereby, valuable benefits due to routine and specific interaction with science and research are pointed out. The toolbox of research procedures available for comprehensive footwear evaluation and development is addressed. In order to systematically improve the functional criteria of authentic and advanced performance footwear, this toolbox combines mechanical, biomechanical, athletic performance, and perception procedures, which nowadays are strongly supported by computer simulation approaches. The needs of specific consumer target groups with respect to gender, age, or skill level are referred to, as well as the specific individual service for elite athletes. Future requirements to improve footwear science, research, and testing in industry and academia are proposed. A learning control section and references are provided at the end of the chapter.

29.1 BACKGROUND

29.1.1 Athletic Footwear

Footwear science addresses aspects of all types of shoes, including dress shoes, working shoes, sport shoes, or medical shoes. However, this chapter focuses on the functional aspects of athletic footwear only, neglecting style and fashion aspects that solely refer to outward appearance issues. Functional aspects of athletic footwear are defined as all shoe modifications having potential to influence objective characteristics as well as subjective perception of human locomotion and human movement. Generally, functional shoe modifications aim to improve three superordinated aspects: comfort, performance, and injury prevention. The inspiring potential of shoe design features to influence these aspects was brought to the scientific community starting from the 1970s and 1980s (Nigg, 2010). The movement mainly originated from three research institutes, the Biomechanics Laboratory at Penn State University (United States), the Nike Research Laboratory (United States), and the Biomechanics Laboratory at the Eidgenoessische Technische Hochschule (Switzerland). The main research focus was on running shoes at that time and initial strong links between the athletic footwear industry and academic institutions were established. Scientific research efforts have been carried out increasingly until today and will go on in the future (Cavanagh, 1980, 1990; Frederick, 1984; Nigg, 1986, 2010). Next to comfort, performance, and injury prevention issues, durability aspects need to be taken into account, which addresses the targeted and expected life cycle period of shoes, but which also refers to gradual alterations of functional footwear properties during regular wear (Wang et al., 2010).

When characterizing target consumers, different skill levels need to be considered. As elite athletes may have highly individual demands of shoe function, personalized footwear accounts for their potentially unique anthropometrics, body composition, and sport-specific techniques. In contrast, common athletes are split into subgroups of gender, age, and skill level to be provided with adequate functional footwear. In addition, cultural and ethnical criteria need to be considered. Males and females differ considerably in their general body biometrics, which are responsible for different athletic performance levels and also specific injury patterns. Thus, it is not surprising that gender-specific biomechanical locomotion patterns were identified (Ferber et al., 2003; Landry et al., 2007a,b). Different biological and physical capabilities were also shown to result in altered playing strategies in ball games (Althoff et al., 2010). Foot morphology was observed to be gender specific already relatively early, and knowledge was enhanced by applying more sophisticated measurement technology in late research (Krauss et al., 2008; Robinson and Frederick, 1990). As foot morphology is also specific to cultures (Mauch et al., 2008), the global challenges for manufacturing well-fitting footwear are obvious. In addition, subjective requirements of different gender and age groups have been addressed in a survey questionnaire about running shoes (Schubert et al., 2011). It should be noted that gender-specific observations have already led to knowledge-based design recommendations on how to create female-specific footwear for running and soccer (Krauss, 2006; Sterzing and Althoff, 2010). Similarly, age-related footwear modifications may be thought of, responding to the development and degeneration of the human body and foot during the human life span.

As athletic footwear is designed for numerous, diverse sports, it needs to account for the various respective requirements. Thereby, each sport can be treated as an individual category, which results in a high number of categories. Integrative approaches identify sports and disciplines that share similar locomotion and movement characteristics, resulting in common overlapping demands. These sports are then grouped into broader and comprehensive categories. Optionally, such integrative approaches may focus on footwear construction aspects or on locomotion type aspects. An integrated comprehensive category for cleated footwear would include sports like soccer, football, rugby, baseball, cricket, and golfing. In contrast, an integrative comprehensive category focusing on locomotion types identifies common important movements for a range of sports and disciplines, such as acceleration, sprinting, deceleration, cutting, turning jumping, or landing. Respective core physiological and biomechanical elements can be extracted and analyzed in order to develop general responding concepts. For instance, basic biomechanical research approaches that address the fundamental circumstances during the push-off and take-off phase of human locomotion are highly beneficial for creating authentic performance track and field footwear. Additionally, gained knowledge is ideally suited to be fed into footwear aiming to provide athletes with a performance edge during various field and court sports. It is noteworthy that such category-based company structures were set up in most footwear companies only during the 1990s. Originally, this was done in an effort to enhance product-related work effectiveness and efficiency.

Athletic footwear also needs to respond to changing environments, for example, changing surface types, as illustrated for tennis and soccer in the following. For tennis, the nature of the game and thus respective footwear requirements differ considerably when playing on hard court in comparison to playing on clay or grass courts. Thus, functionally designed tennis footwear should provide surface specific traction properties providing players with their respective acceleration and deceleration demands. Due to successful development of artificial surfaces and subsequent rule changes by the governing global soccer associations, soccer is nowadays played on natural or on artificial turf. Looking back to the natural grass area, different weather-related surface conditions drove the development of hard, firm, and soft ground stud configurations for responding to hard, dry, and wet surface conditions. For the fairly new artificial turf surfaces, it was shown that footwear construction can adequately respond to this new interface situation by providing players with improved agility running performance and reduced lower extremity loading when wearing adequately designed footwear (Müller et al., 2010b; Sterzing et al., 2010).

29.1.2 Functional Footwear Innovation

Functional design considerations of footwear, have addressed comfort, performance and injury prevention issues ever since. Thereby, innovative structures, materials, smart technologies, and manufacturing methods have been used.

Systematically arranged fixed studs improved functional traction properties of baseball shoes already in the end of the nineteenth century. The general stud concept for cleated footwear to provide functional traction then experienced a significant revision in the midst of the twentieth century. The invention of screw-in studs allowed soccer players to use different stud lengths for coping with temporarily changing surface conditions while maintaining their familiar shoe upper.

Initial efforts to put specific cushioning elements in athletic footwear constructions date back to the beginning of the twentieth century. Rubber and blown-rubber full length insole materials were used in the Converse All-Star vulcanized rubber basketball shoes to provide enhanced cushioning to athletes. It is noteworthy that cushioning is one of the most fundamental footwear concepts trying to accommodate for uneven or hard surfaces and thereby addressing highly desired comfort requirements of athletes. For long, cushioning needs of athletes were only addressed by using different foams as midsole materials. Then, over the years, numerous advanced cushioning concepts were introduced and are strongly associated with respective brands, like the Nike-Air system, working with encapsulated gases, or the Asics-Gel technology making use of the viscoelastic properties of suited materials.

Running shoe construction changed considerably when the first dual density midsoles, originating from collaboration between ASICS and the University of Oregon (United States), were integrated in running shoe designs. Those anisotropic sole units brought a simple but highly influential aspect into running footwear manufacturing.

Geometric modification of running footwear was used to change rearfoot motion characteristics during endurance running. Especially, geometrical varus alignment of running shoes was shown to alter running biomechanics (Milani et al., 1995; Perry and Lafortune, 1995; Van Woensel and Cavanagh, 1992). These early studies analyzed extreme degrees of shoe varus alignment and showed considerably decreased rearfoot motion parameters in runners. Recent research approaches elaborated on the general concept by showing small but systematic biomechanical effects on rearfoot motion control in running shoes with only moderate varus alignment, being suited for everyday use (Brauner et al., 2009; Grau and Horstmann, 2007).

Built-in shoe technology, when considered as a feedback-based mechanical system, was introduced to the athletic footwear market with the Adidas A1. This running shoe obtained and analyzed biomechanical cushioning characteristics during actual running. Based on automated data processing and evaluation, the shoe was capable to adjust its functional cushioning properties at the rearfoot by built-in programming and actuator instrumentation. Smart footwear constructions like this consist of three key components, a sensor unit, a data processing unit, and an actuator unit. Thereby, the process of monitoring, evaluation, and alteration of locomotion patterns is constantly executed throughout exercise. Respective smart shoe designs may have potential to lift footwear to another level in the future, although the ultimate functional and commercial success of these ambitious initiatives has not been proven yet.

In contrast to sophisticated built-in technology footwear, the concept of minimization of footwear, as present with the Nike Free or the Vibram Five Finger, has been showing commercial success. These concepts claim to induce a natural running style to athletes due to their highly flexible midsole and outsole materials as well as their geometrical constructions. However, the terminology of natural running appears to be confusing and will need to be clarified for future discussion of related concepts. When putting barefoot-like running similar to natural running, one neglects that nowadays many people are used to continuous wear of footwear from early childhood on, especially during athletic activities. Thus, it is suggested to distinguish between habitual barefoot runners and habitual shod runners as a first step. The topic of minimization of running footwear has provoked an intense and ongoing public and scientific discussion about the general function and task of athletic footwear for human locomotion.

Generally, functional footwear innovation is an ongoing academic topic and an essential business need for companies in order to maintain or to achieve a certain market position. Thus, anticipation and creation of footwear market demands is a core task for all product-related departments within athletic footwear companies. The innovation process includes all efforts of turning an initial idea into a successful product, ultimately creating commercial value. Thereby, commercial value can be achieved not only by well-selling footwear but also through authentic unique products that are suitable to increase the company's brand reputation. During the process of functional footwear innovation, experimental laboratory and field knowledge is transferred into superior and substantial products by usage of interdisciplinary expertise. This expertise may originate not only from the field of sports science, with its branches of biomechanics, exercise physiology, and psychology but also from the field of engineering, including the areas of mechanics, materials, chemicals, and electronics. The workmanship, knowledge, and experience of podiatrists, shoe technicians, and artisans have to be emphasized as an additional important source for functional footwear innovation. Furthermore, innovative concepts derived from sciences like bionics or biomimics as well as from human motor learning theories are also capable of successfully nurturing product innovation.

29.2 INDUSTRIAL SETTING

29.2.1 Company Departments

Athletic footwear companies require intense and consistent interaction of their specific departments to create well-functioning footwear for the domestic and global markets. A general classification may align departments within the executive level and within the product level (Figure 29.1).

At the executive level, *Sales* is responsible for the development of product distribution channels and the communication on product needs. It explores, establishes, and maintains related business opportunities with wholesale and retail customers, as well as with consumers. *Marketing*, in addition to brand and product promotion efforts, ranging from TV commercials to in-store displays, is responsible for setting the long-term brand and product directions by aligning marketing resources,

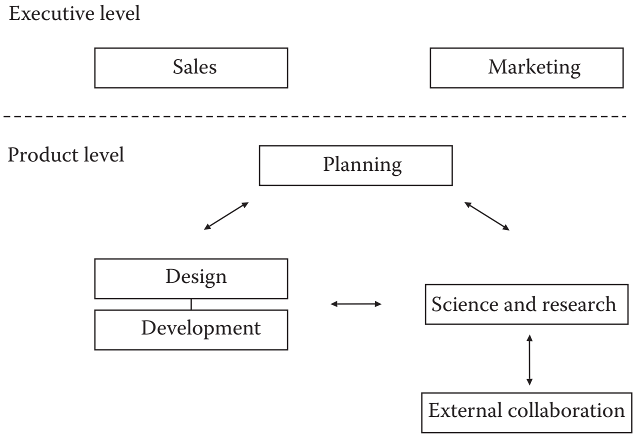

FIGURE 29.1 Company department structure.

competitive advantages, and specific strongholds of the company. Addressing relevant consumer and market necessities, *sales* and *marketing* are responsible to set up the major business directions and to decide on the long-term marketing platform for the company's products. Thereby, an important goal is to establish and preserve an authentic company reputation that ensures positive recognition with respect to product functionality by wholesale and retail customers, as well as by the athletic consumer.

At the product level, all operational steps from initial product planning to final product design and development are carried out in mutual interaction with science and research efforts. Prior to market release, each shoe model ultimately passes through a widely standardized product creation process, the in-line product cycle. The in-line product cycle duration for athletic footwear lasts 18 months, which appears to be a common global standard across athletic footwear companies. The key departments involved in this product creation process are *product planning, product design*, and *product development*, necessarily having well-coordinated interaction all throughout the product creation process. It is highly recommended that *science and research* is involved all throughout the product creation process in order to take over responsibility for all functional aspects of the products by applying objective, valid, and reliable testing procedures. Within the in-line product cycle, *product planning* develops and controls the general product plan, including the product development plan, the product line strategy, the pricing strategy, and also regional product strategies, when applicable. Critically, the product strategy needs to be well aligned with the major business directions and general marketing platform of the company, which is determined at the executive level. Functional considerations of athletic footwear should take a core position within the product strategy as it enhances the potential of footwear products to play substantial roles on the markets, subsequently leading to prolonged and thus commercially more beneficial lifetimes. Therefore, *product planning* should foresee or even try to create future domestic and global market needs by interaction with *product design* and *product development*. Nurturing and supporting these efforts, *science and research* is ideally suited to feed innovative and functional concepts into this process. Thereby, solid scientific proof of such concepts necessarily needs to be established already prior to the initiation of the respective in-line product cycle and should provide the baseline for all subsequent related processes. *Product design* follows up on the set product plan and creates detailed sketches of each footwear product including exact dimensions, color ways, as well as material and manufacturing suggestions. *Product development* then follows up on these sketches by opening respective toolings in order to create prototypes and later on final products in close interaction with the factories. Within a regular in-line product cycle, several prototype rounds are carried out, each allowing for respective testing and subsequent changes to be made.

Continuous interaction following the initial consent about the full product strategy ensures that necessary adjustments can be executed and that the general product plan is viable for all departments involved. *Science and research* takes a specific role prior and within the in-line product cycle as being capable to support the other departments at all stages of the product creation process. Thereby, the genuine scientific knowledge about the functionality of footwear must be already established at the beginning of the in-line product cycle in order to allow handing over the functional technology brief. Located within the company and equipped with the state-of-the-art instrumentation operated by highly educated staff, *science and research* is ideally suited to support numerous related departments of the company by providing functional knowledge and by putting forward innovative functional concepts based on scientific knowledge. Furthermore, it serves as a gateway for valuable external resources due to thoughtfully established scientific collaborations with academic or industrial institutions.

29.2.2 Science and Research Interaction

Within the product cycle, the role of the *science and research* department is clearly confined by supporting the interacting departments with educated advice as well as the conduction of product testing. However, additional goals are broader and show closer links to scientific baseline research in human locomotion and human movement. Thus, related timeframes need to be longer than the fixed product cycle schedules of other departments. Short-term (18 months), in-line product cycle related tasks are predominantly linked to the routine commercial business. Main targets are the final monitoring of functional product quality as well as of respective durability issues of products and materials. Midterm tasks (18–36 months) should focus on systematic product creation processes and can well respond to changing footwear needs according to advanced functional performance requirements, to environmental demands, and also to technical requirements put up by governing bodies of sports associations. Thereby, midterm tasks may follow a basic three-phase structure consisting of status quo analysis, knowledge-based prototype testing, and final market comparison (Figure 29.2).

Status quo analyses should be based on comprehensive testing procedures and serve as an intellectual baseline from which knowledge-based prototypes are created which then are subject to further evaluation. Respective findings are then fed into advanced prototypes until the functional quality of the shoes is on the company's

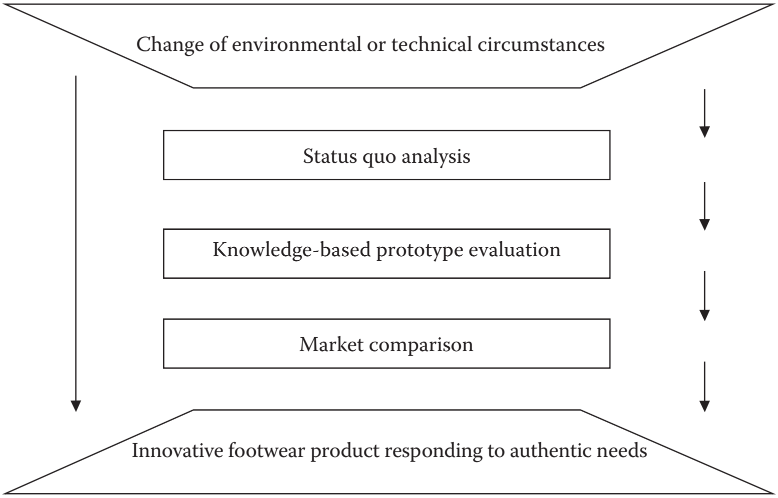

FIGURE 29.2 Midterm innovation structure.

target level. The ultimate goal should always be to establish scientific proof of the functionality of future innovative footwear concepts. Market comparisons are suggested to be carried out at a certain stage to ensure superior function of the respected technology compared to existing products on the market. An illustrative example for a midterm research project is the work on an innovative traction outsole concept for artificial soccer turf shoes (Sterzing et al., 2010). This research effort was carried out in response to the implementation of artificial soccer turf as official playing surface and included the aforementioned three steps, framing a systematic product development effort. The most important benefit of such processes is that solid general footwear manufacturing guidelines can be derived and transferred into a range of shoe models. Furthermore, it is important to understand that additional scientific benefit is gained by providing functional understanding of specific circumstances, which increases the general knowledge of the company.

For the implementation of innovative and advanced authentic performance products, long-term time frames (36 month plus) are recommended. The basic pattern to be followed is to initially use or to generate enhanced understanding of human locomotion and human movement. Based on this, an innovative functional technology idea is needed to be incorporated in athletic footwear design. After initial prototype construction and early evaluation efforts, it is necessary to achieve scientific proof of concept, in a sense of functional validation. Once established, the technology brief can be handed over into the in-line product cycle process (Figure 29.3).

Another important task of *science and research* is to serve as an educative source for company members providing background of general principles of human locomotion and human movement in order to lift up respective company knowledge. Regular educative initiatives in digestible formats provide support and education for staff members from planning, design, and development for an improved understanding of functional athletic footwear needs in general, but also of specific subgroups needs that were addressed earlier. Ideally, planning, design, and development people

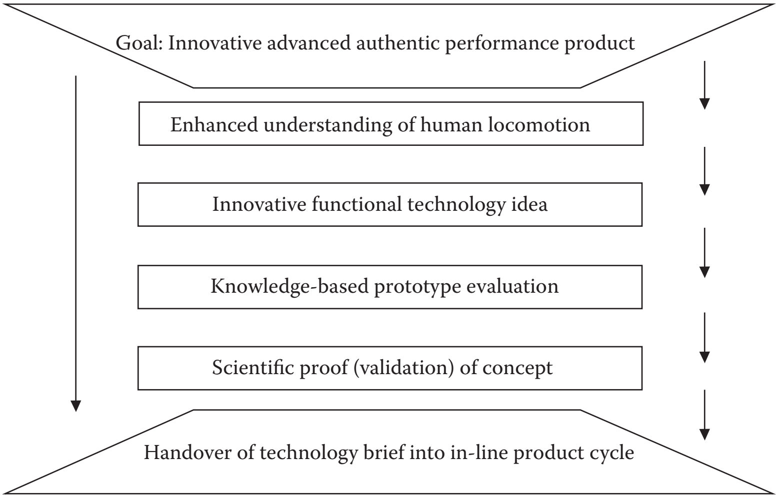

FIGURE 29.3 Long-term innovation structure.

can integrate this knowledge into their daily product-related work. Increased common functional knowledge tremendously facilitates the planning, design, and development efforts during the product creation process and may additionally support sales and marketing of the company's executive level.

29.3 SYSTEMATIC DEVELOPMENT OF ATHLETIC FOOTWEAR

29.3.1 Fundamental Knowledge

To enable comprehensive athletic footwear development based on functional requirements, substantial baseline knowledge about athlete's needs is necessary. Broad game analyses as well as specific locomotion and movement analyses are used to determine objectively the respective sport inherent demands. Thereby, characteristics of single person sports like track and field but also of team sports like various ball games need to be considered. For the latter, frequency and nature of movements need to be obtained, also providing information about their respective importance for game success. Subgroup analyses are recommended to receive more specific information about the effects of different skill level, biometrics, gender, age, playing position, and culture. As locomotion and movement techniques as well as ball game playing patterns may change with time, it is recommended to reconfirm knowledge on a regular basis.

For matching functional athletic footwear design with the subjective needs of atheletes, simple interviews and questionnaires are commonly used practices to gather fundamental insight. Thereby, athlete interviews are mainly used when working with elite athletes as they are often provided with individually modified footwear. When general knowledge about athletic footwear demands is required, questionnaires are a useful tool, especially when aiming at gathering substantial information of larger subject groups (Brauner et al., 2012; Schubert et al., 2011). Large-scale surveys allow further analysis of subgroup demands according to gender, age, skill level, or playing position. For the investigation of geographic- and culture-specific requirements, suitable global locations need to be selected for execution of data collection, an ideal opportunity for making use of external collaborations. Well-structured questionnaires provide highly valuable information about numerous footwear aspects like subject characteristics, consumer habits, shoe property importance, desired degree of shoe properties, shoe problems, or foot problems. Such knowledge is an important asset to create a baseline for the planning, design, and development of athletic footwear, ensuring that product creation from the very beginning is aligned with subjective needs of athletes. As athletes' perspective toward footwear requirements may change with time, it is recommended to reconfirm knowledge on a regular basis. In common, game analyses, movement analyses, as well as athlete interviews and questionnaires allow building up a specific footwear feature framework for the different categories; thus, they are crucial tools to start with in the general product creation process.

29.3.2 Comprehensive Footwear Evaluation

Based on earlier works of various researchers, a comprehensive approach incorporating diverse testing procedures is endorsed for the evaluation of athletic footwear. In addition to mechanical, biomechanical, athletic performance, and subjective perception testing procedures, computer simulation testing procedures have to be mentioned (Figure 29.4). In the following the various procedures are characterized and their respective benefits as well as their mutual levels of interaction are described.

Mechanical testing procedures are objective measures to provide information about the material characteristics of athletic footwear. Common mechanical testing procedures for athletic footwear focus on impact, translational and rotational traction, torsion, and flexibility characteristics of footwear. Thereby, materials can be tested as isolated pieces as well as already built-in structures. It is recommended to ultimately test the mechanical function of materials when being built in, as material characteristics may be affected by interfacial and assembly conditions with other components or simply by the manufacturing process. An advantage of mechanical

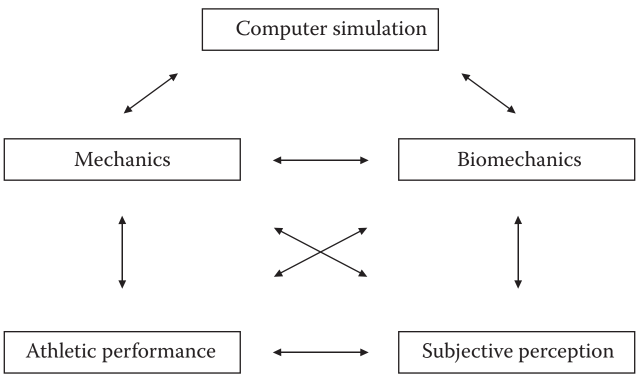

FIGURE 29.4 Comprehensive footwear research and testing structure.

testing is their high reliability and objectivity. A disadvantage is the relatively low validity with respect to actual human locomotion and movement, as commonly used mechanical testing procedures often do not account for the complex loading conditions and do not account for any adaptation processes that are observed during actual human locomotion. In an effort to close this gap, recent research tried to very precisely simulate the biomechanical loading characteristics during foot strike in heel to toe running, when applying mechanical running shoe testing procedures (Heidenfelder et al., 2011). Results indicate the possibility to obtain similar shoe alteration effects for mechanical compared to biomechanical alteration when applying mechanical loading profiles that closely reflect actual biomechanical loading over the suggested life cycle of running shoes. These findings should encourage similar research, potentially leading the path to further valid, subject independent mechanical testing procedures of shoe characteristics in the future. It should be acknowledged that only the recent availability of advanced and also financially affordable mechanical testing instrumentation formed the basis for the progress made.

Biomechanical testing procedures evaluate footwear function by subject involvement. Although field tests are conducted in some occasions, biomechanical footwear evaluation is usually performed in laboratory settings using measurement equipment like force plates, pressure measuring systems, motion analysis systems, muscle electromyography measuring systems, and others (Payton and Bartlett, 2008). In contrast to mechanical procedures, biomechanical testing allows to observe functionally important adaptation mechanisms of subjects due to different footwear or other environmental conditions. Additionally, variability of human locomotion and movement between and within subjects can be analyzed by biomechanical research procedures. For long, variability of locomotion and movement was regarded as non-beneficial when evaluating athletic footwear function and study protocols were set up in highly standardized manners. Currently, the perspective on human variability in locomotion and movement is shifting. Variability is now regarded to be rather functional in many athletic circumstances and potentially beneficial by itself, thus becoming an increasingly popular research topic with high relevance for the design of athletic footwear. Naturally, these issues have to be addressed by use of biomechanical research procedures.

For athletic performance testing, straightforward measurement protocols evaluating ultimate performance variables are suggested. As athletic performance is a main goal when constructing athletic footwear, the ultimate success margin for the athlete should be objectively proven. Objective benefit of a certain shoe model can be displayed by measuring time, speed, or oxygen consumption during sprinting, agility running, or endurance running (Frederick, 1984; Nigg, 2001; Stefanyshyn and Fusco, 2004; Sterzing et al., 2009). Ball kicking velocity and accuracy in soccer may serve as additional examples for the possibility to quantify athletic performance benefits, obtained by use of adequate footwear (Hennig and Sterzing, 2010; Sterzing and Hennig, 2008). Thereby, the general goal for athletic performance testing with respect to footwear is the objective verification of a performance margin one shoe model might have over another.

Subjective perception testing asks for subjects' individual opinion toward a specific shoe model or single shoe features. It is critical to distinguish two major approaches of subjective testing, the perceived intensity and the preference of these features (NSRL, 2003). The former asks for the plain degree of a certain shoe feature, for example, hard/soft for cushioning or high/low for traction, while not specifically aiming to get a judgment about respective suitability. The latter asks for information which shoe condition is actually perceived to be more suitable and thus preferred. Generally, all shoe properties can be included in subjective perception testing. However, not all shoe properties can be detected by subjects due to neurophysiologic or other constraints, as shown for rearfoot motion (Brauner et al., 2009). In contrast to all other testing methods mentioned, during subjective perception testing subjects themselves are the measurement instrumentation. The human sensory system receives and transmits objective physiological stimuli that are transferred into subjectively interpreted opinions when entering the cerebral level of the human nervous system. Thus, subjective perception testing is highly dependent on subjects' past experiences as shown for running shoe fit testing (Kouchi et al., 2005).

Computer simulation has become an increasingly important research tool in footwear science with continuous advancement driven by numerical techniques and computer technology. The finite element method, as a computational approach, was introduced in the 1970s to analyze characteristics and behavior of plain mechanical structures. The ability to provide realistic simulation even when considering highly sophisticated structural and material as well as specific loading and boundary conditions made the finite element method a versatile tool for biomechanics and footwear applications (Cheung et al., 2009). Computer-aided engineering (CAE) techniques allow rapid change of input parameters to analyze their subsequent effects in a virtual simulation environment without the need of conducting actual experiments. For instance, the effect of contour and material of foot orthoses on plantar peak pressures can be assessed and optimized to a large extent by using finite element simulations without time and cost intensive experiments that coincide with related construction requirements of orthotic prototypes (Cheung and Zhang, 2008). Moreover, finite element analysis provides additional insight into the distribution of internal loads and deformation of biological and mechanical structures or systems being modeled (Cheung et al., 2009). Obtaining such knowledge was formerly usually associated with material destruction or at least complicated invasive experimental methods, sometimes even impossible. Currently, footwear companies increasingly apply CAE approaches for evaluation and design of footwear or its functional components. In fact, computer-aided design (CAD) approaches, only focusing on the appearance and dimension as well as related manufacturing of footwear will no longer be sufficient to fulfill the needs of modern footwear research. Practically, CAE approaches effectively cut down the time and cost of footwear research and development procedures by reducing the frequency of retooling and shoe fabrication for prototyping and mechanical testing, thus ultimately the cost and time of product creation processes.

Comprehensive application of the introduced testing procedures is suggested as respective single findings are not necessarily well aligned. For instance, the sole application of mechanical testing procedures turned out to be insufficient for identification of optimal outsole traction configurations for soccer players. It was shown that an increase of mechanical available traction above a certain level does not result in enhanced biomechanical utilization of traction and enhanced athletic performance

(Luo and Stefanyshyn, 2011; Müller et al., 2010a). The rationale derived from these studies is that optimal levels instead of maximum levels of mechanical traction are beneficial for the athlete, as otherwise athletes adapt their locomotion patterns, probably due to injury prevention considerations. For the dependency of athletic performance and respective subjective perception, controversial findings can be referenced as well. It was shown that subjective perception of athletes can (Sterzing et al., 2009), but does not need to (Sterzing and Hennig, 2008; Sterzing et al., 2011), reflect objective athletic performance measurements.

In common, the introduced comprehensive footwear evaluation and testing approach allows strategic and systematic development of functional and innovative footwear. Mechanical testing provides objective and reliable information about functional and structural material characteristics. Biomechanical procedures deliver objective information about shoe functioning under actual influence of the athlete by consideration of movement adaptation mechanisms and responses of the biological human system. Computer simulation serves as an adjunct to the mechanical and biomechanical testing approaches by identifying suitable engineering designs of different footwear constructions and materials. Athletic performance testing examines the ultimate performance output of athletes related to different footwear conditions. Subjective perception testing shows how footwear performance is perceived by subject groups or individual athletes, which plays a crucial psychological role when trying to achieve maximum performance in competitive sport activities.

29.4 EXTERNAL COLLABORATION

29.4.1 Interaction Types

A footwear company has various opportunities to interact with external research institutions for enhancement of its scientific research level and to foster functional product innovations. Thereby, external collaborations comprise not only academic institutions but also other private or government bodies and are naturally coordinated by the *science and research* department. Among others, a basic interaction aspect is the mutual transfer of knowledge between the two research partners (Figure 29.5).

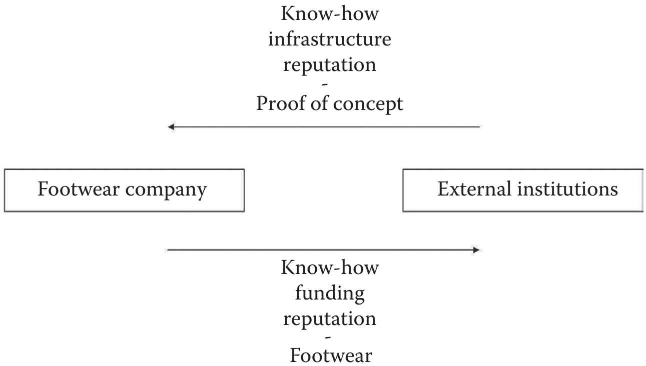

FIGURE 29.5 Interaction of footwear companies and external institutions.

There are various ways for interaction with external collaborators. The company can approach collaborators asking them to carry out specific research tasks according to a set and internally established research protocol. This approach would mean to use human as well as infrastructural resources of an external setting. Another approach is to assign a general and open research topic to external collaborators and ask them to develop a respective research design, which should be subject to mutual finalization prior to be carried out. Here, the external partner is required to provide the research design, results, related interpretation, and future implications for athletic footwear. In addition, external institutions or researchers themselves may approach footwear companies by introducing innovative conceptual ideas and products. In this case, the company needs to evaluate the general quality level and to explore potential research and business benefits of the external collaboration request. On the one hand, the company may benefit from such immediately usable or more readily transferable knowledge with respect to product development. On the other hand, the company is put in a rather passive position, regarding decisions on business opportunities and credibility of research concepts or products without authentic ownership of the research ideas and knowledge. Whereas the first interaction pattern resembles rather an outsourcing of infrastructural and human capacities, the latter two are more useful to bring external technical know-how into the company. However, this know-how needs to be carefully aligned with the company's business, research, and product directions. In order to make efficient use of external knowledge, the company has to ensure that the knowledge provided is fully understood by company's staff members. It is highly recommended to foster continuous mutual interaction between the company and its external research partners. Thereby, ongoing knowledge sharing supports the buildup of scientific knowledge and fundamental understanding within the company, which is of long-term benefit.

29.4.2 General Considerations

There are also more general opportunities to interact with the public academic domain, such as participation in scientific conferences or open product design competitions. Participation as sponsor in these events may be characterized as taking a rather passive and observational position. In order to enrich the interaction with the academia, it is suggested to take more active roles by sending delegates to suitable conferences and presenting parts of the company's nonconfidential research work, which is beneficial to the scientific reputation of the company and its products. Another frequently used possibility for external interaction is the appointment of internships, master or doctoral theses, as well as postdoctoral positions to suited students or scientists from academic institutions. In case these types of interaction are accurately prepared and executed in a responsible manner, highly valuable results can originate, being of mutual benefit for the company, the respective academic institutions, and the involved individuals.

When collaborating with external academic institutions confidentiality, publication, and intellectual property become an issue. An important goal of universities is to publish scientific knowledge during conferences as well as in scientific journals. However, this may be contradictory to the company's internal goals and policies.

From a company's perspective, publication of knowledge is twofold. A company may want to use publications in order to emphasize the existence of a strong scientific background within the company. Another goal is to show that athletic footwear is truly functional by providing proof of general concepts that are implemented in their footwear. When agreeing to publication, it has to be kept in mind that published knowledge is no longer patentable. Thus, companies will have to file patents of their product designs or concepts prior to publishing related findings either by them or by external research partners. Therefore, a publication delay of scientific findings is usually enforced in order to preserve intellectual knowledge as long as necessary with respect to commercial and business requirements. To some extent, a company may want to use publications in order to show superiority of their products in comparison to their competitors. However, this approach is recommended to be only used with caution, for the following reasons. Such type of knowledge published is commonly regarded to be biased by nature, as a company would only be willing to go public with positive results, dropping those findings showing that competitors' shoes have better function. Therefore, general credibility of these publications appears to be rather low.

For collaborative projects, especially for those involving deliverables with a transfer of technology or concept, which has the potential for commercialization, a negotiation process regarding the share of intellectual property between the company and the external institution needs to be carried out. The chance and result for a successful agreement usually vary from case to case, depending on the nature of the collaborative work and funding support defined by the company as well as individual regulations of academic institutions. Therefore, mutual agreement on intellectual property and related share of benefits should be reached prior to commencement of any collaborative project.

Generally, major goals of companies seeking external collaborations are to make use of the external infrastructure, intellectual input, and reputation of academic research institutions. In order to identify an appropriate academic research institution for such collaboration, it is recommended to have thorough understanding of the resources and strengths of the academic institution. A review of the academic track records and latest published work of the research team as well as on-site visits prior to engagement in research collaboration is of utmost importance for the company to find out the respective dedication of the institution for conducting industrially initiated and mutually beneficial footwear research.

29.5 FUTURE CHALLENGES

Industrial and academic footwear research institutions are challenged by current literature contributions controversially discussing the general concepts and usage of athletic footwear (Lieberman et al., 2010; Nigg, 2001; Richards et al., 2009). It is acknowledged that contradicting findings of footwear research have initiated broad discussions about the value of footwear science and research. An illustrative paradigm is the research area of rearfoot motion. High pronation variable value are associated with an instable foot strike pattern in running, which was linked to overuse injuries in endurance running even though there is still lack of scientific evidence to confirm this theoretical construct. Nevertheless, the assumption that instable rearfoot motion leads to overuse injuries in runners has led to tremendous efforts to construct more stable running shoes accompanied by marketing campaigns educating the running population about the importance of rearfoot stability in endurance running. However, related injury rates were not observed to decrease. It became obvious that prospective scientific research on the epidemiology of running injuries is missing and that current opinion is based on retrospective data only. Thus, injury occurrence and prevention aspects linked to athletic footwear need to be investigated by large scale prospective studies with injury numbers and severity as ultimate outcome variables to be analyzed (Hein et al., 2011; Nigg, 2001). As footwear companies in their daily, business-driven routines often lack respective time needed for such large-scale research efforts, academic institutions should take over and lift related knowledge on a more substantial level.

Another important aspect of future footwear research is the ongoing need for reviewing the current research methods (Oriwol et al., 2009), accompanied by the development of advanced research methods including the critical review of measurement environment and measurement awareness. It is likely that advanced data processing and statistical methods are able to improve the substance of scientific research results.

QUESTIONS

29.1 Explain what is meant by "functional aspects of athletic footwear."
29.2 State five significant athletic footwear concepts brought to the market until today.
29.3 State the four company segments primarily involved in the product creation process.
29.4 State the three phases of a midterm innovation structure, responding to changing environmental or technical circumstances.
29.5 State the four phases of a long-term innovation structure, aiming at the creation of innovative advanced authentic performance products.
29.6 State six footwear-related subgroup criteria for categorization of athletes.
29.7 State six sections of questionnaires when collecting baseline data of athletic footwear requirements.
29.8 State the five research approaches for systematic and comprehensive development of athletic footwear.
29.9 State the two major approaches of subjective perception testing.
29.10 State three benefits of companies due to external collaborations.

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