TECHNISCHE UNIVERSITÄT MÜNCHEN
Fachgebiet für Sportgeräte und Materialien

# Enhancing Sport –
# Sports Technology Design in the Context of Sport
# Motive, Motion Task and Product Feature

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Munich, June 2010 Maximilian Müller

“Sport unites people little else can.”

Nelson Mandela

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# 1 Introduction

Why do people exercise? And how can sports technology be designed to enhance and support this activity? A major challenge in the development of sports technology, and the basis for this thesis, is matching desirable emotional experiences in a sports activity to their realization in terms of a specific product design. This thesis presents research that was carried out to enrich the technological approach of product design in the field of leisure sports with the potential to quantify selected aspects of human behavior and motion tasks. In addition, the findings are embedded into practical work by introducing a design example that utilizes engineering and information technology to provide training support for skiers. This introduction provides background on two fields of interest before detailing the specific aims of this thesis.

The nature and purpose of sports technology is subject to ongoing renewal processes and expansions. These changes are connected to the embedment of sports technology in the socio-culture of sport and the related emergence of new forms of sports activity because of the increased popularity of leisurely practiced sports. For example, the common expression “sports equipment” may be outdated because of its diversified applications and the related increase in the importance of technology in development. Common outdoor sports, such as skiing or mountain biking, implicitly require a considerably more sophisticated set of sports technology compared to traditional sports such as gymnastics or athletics (Figure 1-1).

*Figure 1-1: Sports technology past and present – rack for gymnastics and full-suspension mountain bike.*

Several decades ago, sports equipment was considered an opponent to the athlete because of the strict rules of motion. Today, sports technology can be viewed as an extension of the athlete’s body, enabling a fusion of human and object and allowing the spontaneous generation of new movements (Gebauer, Alkemeyer, Boschert, Flick, Schmidt, 2004, pp. 69ff).

Despite the advances in sports technology, the sports activity is still performed by the athletes themselves, and it is the athlete who utilizes sports technology in the mastery of his sport. Each athlete has his own motivations for participating in his sporst inlcuding to have fun, to challenge himself, or to maintain his health or physical condition. Athletes may enjoy exercising alone or in groups and extensively or intensively. Similarly, sports technology is utilized to serve several purposes: to enhance performance, to increase safety or to provide support. Based on the range of applications of sports technology, the design of sports technology clearly exceeds the coverage of traditional engineering methods and expands to include a variety of other human science disciplines that help to clarify the interrelation of athletes, motion and technology. The related areas of interest within the field of human science include sports science and physiology.

The idea that many disciplines influence sports technology design is based on considerations that were made in connection with the work in several research projects. Motivation for the present research is based in part on the following observations:

- Change in the socio-cultural dimension of leisure sports:
  In Germany, the age structure of people engaged in sport changes with the shift in demographics towards older ages. However, youth driven subcultures remain the backbone of new trends in sports. Outdoor sports have seen an increase in popularity in recent years. Generally, the penetration of sporting goods (e.g. sportswear) into everyday life and the role of sport in society are rising. To adjust product features and, specifically, the functionality of sports technology to these tendencies, it is important to embrace both athletes' motivational background and preferences. When considering these insights in practical design work, it is important to methodically connect the motion task (sport), motive (athlete) and functionality (sports technology). To date, approaches have only focused on the evaluation of product features or biomechanical mechanisms.
- Infrequent transfer of scientific findings and methods to leisure sports:
  In sports science and psychology, there are many methods available for evaluating motor activity, biomechanics, physiology and motivation. However, a transfer of these methods to applications in leisure sports is rare. For example, the entire budget of the German Federal Department of Sports Science is given to projects associated with evaluating professional sports. Because the insights are predominantly based on testing and measurement methods conducted on an athlete or a piece of sports technology, a major challenge is the complexity of the athletic performance or environment occurring during measurement. The majority of methods implemented are very cost-intensive in terms of the effort for application, the price of measurement tools, and the effort for data analysis and interpretation. The application of such rigorous methods and scientific study can, however, be translated to leisure sports and may facilitate the development of innovative products if certain preconditions and simplifications are mastered.

- Reluctant application of promising new technologies to sport:
  In contrast to the consumer electronics or automotive industries, the sports industry does not respond to technological innovations comprehensively. According to Hanna (2006), this lack of response may originate in underfunding of the design departments (sports companies only invest 1.5% of their turnover into research and design) or in a general lack of know-how. Product novelties are almost exclusively limited to improvements in materials (e.g. the application of carbon fiber for bicycle frames), and less often in advances in product functionality. The benefit for the athletes is often questionable (e.g. questionable safety for handling carbon fiber parts compared to noticeable effects for the user). Experience in current research gives basis for the assumption that the opportunities of new information technology and sensor systems, particularly with respect to their application in sports technology, are currently underestimated. These technologies could act as a catalyst for the transfer of knowledge from sports science to the field of leisure sports.

In the following, three brief examples are described to illustrate the aforementioned areas of difficulty. These examples are taken from research that was conducted in the context of this work and information that is commonly available in the media.

Example 1:

In 2005, a manufacturer designed and produced a new type of metal ski edge with the goal to considerably improve the edge grip during turns (Figure 1-2). The company initiated an evaluation project in which two subject groups composed of leisure skiers were equipped with skis and completed a predetermined test cycle. One group was given the ski with the new edge design and the other group was given a placebo ski that looked similar to the new ski. The test was statistically evaluated and the results revealed that the subjects were unable to observe a significant difference in the effect of the skis. This example demonstrates that the evaluation of the effect of a certain sports technology design is an important aspect with respect to the addressed user group. It is likely the skis were tested by the people within the company or by designated testers who may have confirmed the improved grip effects of the new skis. However, the leisure skiers the ski was originally designed for did not report "feeling" any difference in grip during turning. Controlled and unbiased evaluation during early phases of product design to gain feedback from the target users of the ski may have prevented such a problem. The ski is no longer on the market.

*Figure 1-2: Ski with special edges whose effect was not tangible for leisure skiers.*

Example 2:

A project was designed with the goal to optimize a racing bobsleigh (see Figure 1-3 left). Bobsleighing is considered a very demanding sport in regards to the physical and cognitive strains on the athletes because of the extreme speed in the ice tunnel (around 130 km/h). Therefore, apart from pure performance parameters such as speed, the handling of the bobsleigh, i.e. the response to steering and the damping of

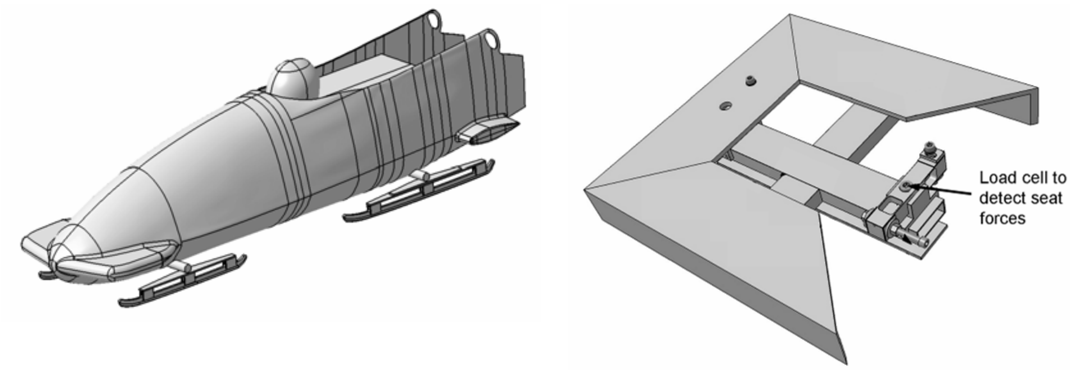



*Figure 1-3: CAD models of a racing bobsleigh (left) and exemplary detail of the measurement cell that was installed to detect the seat forces during downhill.*

the frame, is critical. In accordance with the project initiators, a comprehensive set of measurement tools was installed in a bobsleigh. Sixty-four sensors were installed, at a cost of approximately 25,000 €, to measure the forces on the sleigh's runners' axes and other parts of the frame (Figure 1-3 right), and to determine steering angles, steering forces and air resistance.

Following data acquisition, it was found that the athletes were not able to describe how the frame and the other parts of the bobsleigh should be optimized. When asked if it should feel “stiff and rigid” or “soft and smooth”, athletes frequently responded that the sleigh needed to feel “good and fast”. Ultimately, 80% of the acquired data was discarded because it was irrelevant. This illustrates the point that even when sophisticated measurement methods are available, the acquired data is meaningless if specific and objective goals are not carefully determined. A model or idea of the motion task and the specific aims must be determined *a priori*. Particularly for leisure sports applications, where the users (i.e. the athletes) usually do not have expertise in measurement methods, sports technology must also be intuitive and simple.

Example 3:

An electronic ski binding was developed to indicate the current adjustments of the binding. The potential benefit of the product was clear, but development costs and the complex, hand-made production process forced the price of the binding to nearly 1,000 € – termed the “Maybach price” in the specialist press. This example illustrates that while electronic systems may have a place in sports technology, market factors must be considered. Therefore, as increasingly advanced products and applications are realized, a thorough financial analysis is critical before introduction to the volume market.

In this thesis, sports technology design is studied with an emphasis on the importance of product features and functionality. The role of sports motions and their interdependencies with the user (i.e. the athlete) are further considered. The findings are based on investigations involving two leisure sports: skiing and mountain biking. These specific research projects were selected because of the considerable amount of sports technology involved in these two activities and the consequent potential for product innovation. In particular, the research was aimed at transferring training methods and engineering knowledge from performance sports to leisure sports. Skiing is a sport where a general lack of innovations and a shrinking market in terms of sports technology seemed apparent. Cycling, on the other hand, is a sport that has experienced rapid growth in recent years. These contrary tendencies promised interesting outcomes for research in sports technology design with respect to the different market preconditions. In addition, the clarification and verification of these preconditions were considered in this project. Contributions to three major research topics are made:

- Instances of sports technology:
  The importance of different product features and the peculiarity of the athletes’ sport motives concerning a specific motion task (e.g. skiing) are of interest for the task clarification in product design. To date, this has not been adequately evaluated.
- Matching functionality, motion tasks and the athletes’ motivational background:

As illustrated in above examples, not only the comprehension of the coherences between these instances but also the methodical evaluation of single aspects such as the athletes' emotional state in connection with the used sports technology and with respect to a certain motion pattern (e.g. ski turns) are challenging. To date, a comprehensive model that unifies the different aspects and facilitates its comprehension for specific design tasks has not been established. The dominant motives for participation in leisure sports, such as enjoyment or fun experience, have not been considered for quantification in terms of sports technology design.

- Utilization of sensor systems and information technology for training support in leisure sports:
  Today, the utilization of mechatronic systems for training support is polarized and limited to relatively simple applications (e.g. heart rate monitors). The creation of mechatronic sports technology that provides interpretation of sophisticated motion data in a concise and logical way for training support is a completely new field. However, design of such products must take into consideration the challenges that previous sports technology products have encountered (as discussed above) and comply with athletes' needs and expectations (e.g. regarding training effectiveness).

To pinpoint the contribution of the present research in the process of product design, it is helpful to put it into the context of known procedural models. Some authors and institutions have published procedural models to clarify the problem solving process and the stages of ascertainment in product design. Established models can be found in the elaborations about engineering design (Pahl et al., 2007, pp. 125ff), the V-model for the design of mechatronic systems (VDI 2206, 2004), the general approach in developing and designing (VDI 2221, 1993), the approach towards integrated product design (Ehrlenspiel, 2007), and the approach for the design of technical products (Lindemann, 2007). The outcomes of the present work can be used to clarify input parameters for new designs, for optimization, or for the evaluation and comparison of existing products. Compared to the design of other technological products, the emphasis on the athletes' (users') behavioral aspects is of unique importance in the context of sports technology because of the fact that the sports motion task itself is only the path to the end in the utilization of these products. Consequently, physical activity (and related aspects such as safety) represents the purpose of design. The outcomes are then the contributions to the definition of requirements, the assessment of product properties, and the verification of goals in Lindemann's general problem solving model (which emphasizes the interdependencies and iterations between the instances). Related areas are shaded in Figure 1-4 (left). With respect to a more procedural view according to VDI 2221, the clarification of tasks and functional structures can be supported and verified upon product validation as a functional model or prototype (steps one, two, five and six in Figure 1-4, right).

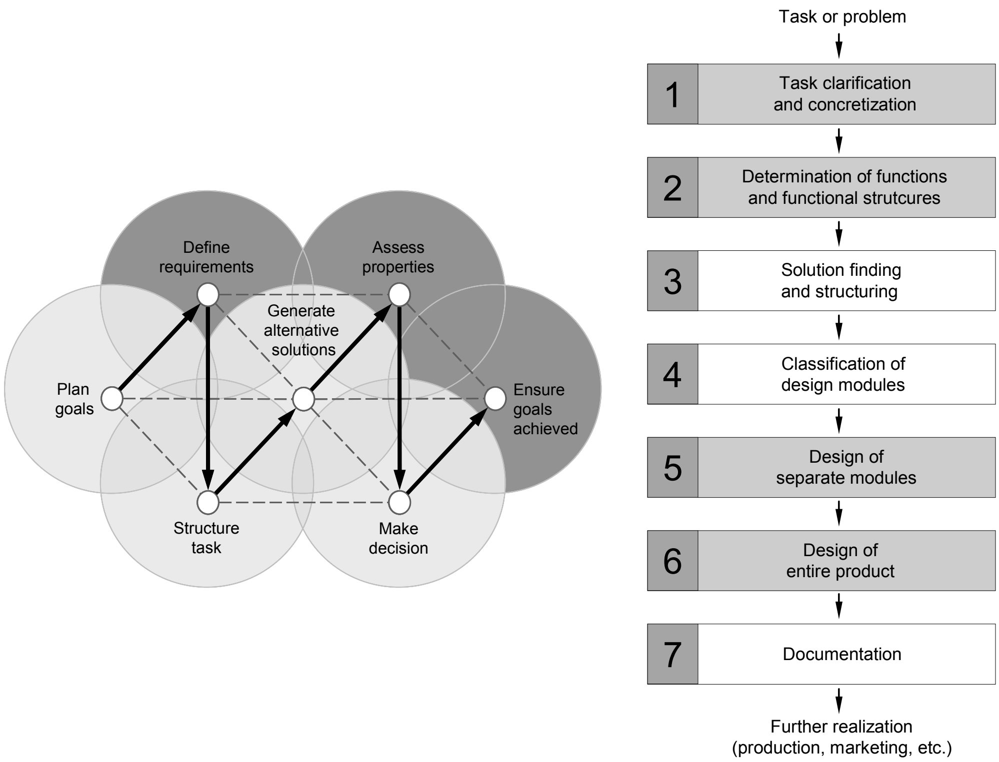



*Figure 1-4: Munich procedural model as a model for problem solving (left, according to Lindemann, 2007) and the general model of the product design process (right, according to VDI 2221, 1993). The outcomes of the present research contribute to the darkened steps in the context of sports technology design.*

The thesis is structured as follows:

Chapter 2 begins with an overview of the context of sports technology design with respect to the socio-cultural dimension of sport and the approaches that were taken by other authors to embrace the specific aspects of product design in the field of sports technology. An outline for the classification of these aspects is detailed to provide a context for the contributions of the present work. Unsolved design aspects and problem definitions in sports technology design are highlighted from the viewpoint of scientific experts. The chapter concludes with the formulation of the research questions that are addressed in subsequent chapters.

Chapter 3 states these research questions and highlights them from the standpoint of sports equipment manufacturers, sports retailers and athletes. The purpose of this study was to explore similarities and discrepancies in the views of parties associated with sports technology innovations. The surveys conducted were based on two example sports: skiing and mountain biking. In general, the results serve as a valuable database concerning the importance of selected product features (i.e. functionality and other aspects such as visual appeal) and sport motives. In particular, the results were used as further input for the development of a strategy to address the issues related to product design and development outlined above.

Chapter 4 introduces the concept of a holistic sport model that accounts for the aspects motion task, motive and functionality with respect to sports activity and sports technology. Further, a theoretical background is provided on motivation psychology in sports. On this basis, a methodical approach is presented and verified with the goal of quantifying the effect of lateral acceleration on perceived gratification in a leisure sports context.

Chapter 5 applies the concepts introduced in the preceding chapters to the field of mechatronic sports technology. The development of a training feedback system for skiing is presented that takes into account the motivational background in skiing, specific motion tasks, information perception and learning processes in sport. The relevance of this design is finally evaluated regarding training effect and perceived enjoyment in ski turns.

The results of this thesis are summarized in Chapter 6. Based on this summary, potential future research topics are given.

The Appendix contains additional materials and results pertaining to the studies that were presented in this work.

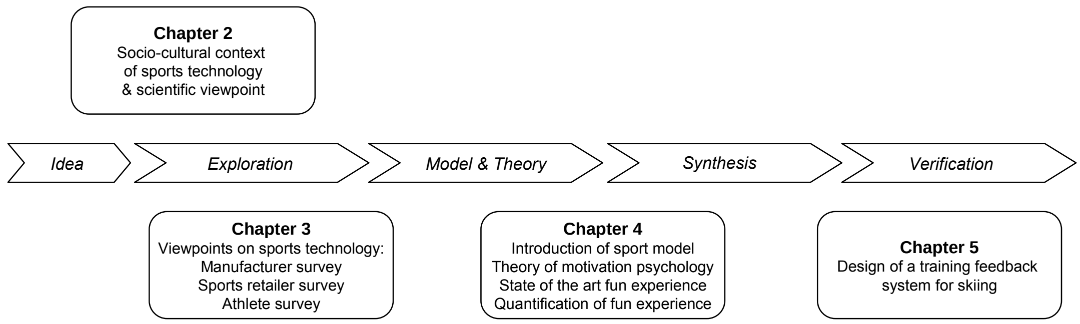



*Figure 1-5: Structure of this thesis.*

The materials utilized throughout this thesis were the products of various collaborative research projects. Relevant references are indicated in subsequent chapters.

# 2 Opportunities and challenges in sports technology design


The field of sports technology is as diverse as its underlying discipline sport. Investigations of specific aspects of sports technology design require context and orientation in this field. In this chapter, the subject of sport and major trends in sport will be defined and highlighted. This discussion will include promising research opportunities within the field followed by a survey of experts in related scientific fields that revealed some unsolved core items of interest with respect to the present work. The chapter concludes with a summary of the findings that motivated the research questions addressed in the subsequent sections.

## 2.1 The context of sports technology design

### 2.1.1 Definition of sport

Reasoning about the interaction of sport and technology requires a definition of the underlying domain – sport – itself. However, the definitions of sport and its context are just as varied as the myriad sports that people play, and currently no commonly accepted definition exists. The major problem in defining sport is that the sport reality, that means what is perceived as sport by the society, is evolving. Hence, the definition of sport always faces the question of whether newer trends and constitutional elements are adequately defined. The comprehensive literature research regarding the definitions of sport conducted for this thesis can be found in Appendix 8.1.

The advisory board of the German Sport Association (DSB) specified that sport can be described through its variety, characteristics, aims and goals. Such descriptions can be obtained from the real world of sport (Deutscher Sportbund, 1980, p. 437). On the basis of the DSB announcement, Hägele (1982, pp. 195ff) specified some aspects of sport. Beyond this, sport has a social function as a means of self-realization. Performance and competition should always be related to the individual – it is the experience of performing, not the result itself, that is crucial. With this in mind, beginners are also included in the definition and understanding of sport. This has particular importance for the present work, as it focuses on leisure sports. Hägele's three level model of sport is characterized by an authentic core level of sports ideals (motoric activity, performance display and meanings of sport such as self-realization and social interrelations), the level "reality of sport" (representing the current position and understanding of sport), and the level of aspects that are excluded from sport. Hägele's view shows an obvious gap between the ideals of sport and the practiced reality: Which types of activity should be called sport? Is competition a precondition for an activity to be called sport? Heinemann (1998, p. 33) named two specific reasons for the controversy discussion. First, different groups or institutions, for instance, have different viewpoints regarding sport. A walk can be considered sport to one person while sport for another person may be nothing less than training for a marathon. Second, common conceptions of sport are changing with time. The understanding of sport 30 years ago is considerably different from our understanding of sport today. Accordingly, sport as a social construct is created from the field of different contexts in which an activity is defined as sport. These considerations, along with contributions from other authors in the sport and sport technology literature, serve as a basis for defining sport in the context of this thesis. The definition of sport used in this thesis is provided in the term description box above.

*Own definition from literature findings*

**Sport (also: leisure sports)**

Sport is the nonutile cultural field of body-oriented activities in which humans voluntarily interact with each other or with nature by fair means in exercising their skills or competing to achieve artificial motoric tasks in terms of performance display primarily for reasons of enjoyment or self-realization.

In addition to defining sport, it is important to establish a description for people who are actively engaged in physical activity. While there appears to be no clear differentiation between the different synonyms used to describe "people participating in sports", the terms "athlete" and "sportsman" are most frequently applied to describe these individuals. Although "athlete" is commonly used to describe an individual involved in performance sports or a competition, this term is used more widely to define people engaged in physical activity for the purposes of this thesis (see term description box on the right).

*Term description*

**Athlete**

„An athlete is a person who participates regularly in a sport."

### 2.1.2 Megatrends in sport

Sport today is a medium of very diverse socio-cultural importance. Characteristics of sports technology and the constraints and potentials for the design of sports technology can be better understood when considered with respect to the socio-cultural background of their environment of usage. Accordingly, strong trends can be observed at present (Baun, 2004) which demonstrate that the sport phenomenon is undergoing change processes (Table 2-1). General tendencies are further discussed

*Table 2-1 : Megatrends in sport (according to Braun, 2004)*

| *Megatrends in sport* | | |
|---|---|---|
| | *Quantitative aspects* | *Qualitative aspects* |
| *Macroscopic level (society)* | Expansion of sports culture | Pluralization of sports culture |
| *Microscopic level (individual)* | Normality of sports engagements | Individualization of sports engagements |

by other authors (e.g. Nagel, 2003; p. 65, Schwier, 2003; p. 18f., Opaschowski, 2000, pp. 61ff; Rittner, 1998). In the following, the four main statements and corresponding figures will be discussed.

Expansion of sports culture:

Participation in sport has generally expanded widely in Western societies, specifically in Germany, since the mid-20th century. This trend is often referred to as the expansion of the sports culture. Figure 2-1 illustrates that the proportion of people regularly participates in sports activities in the German society increased by approximately 20 % from 1950 to 2006. Although the absolute numbers may vary

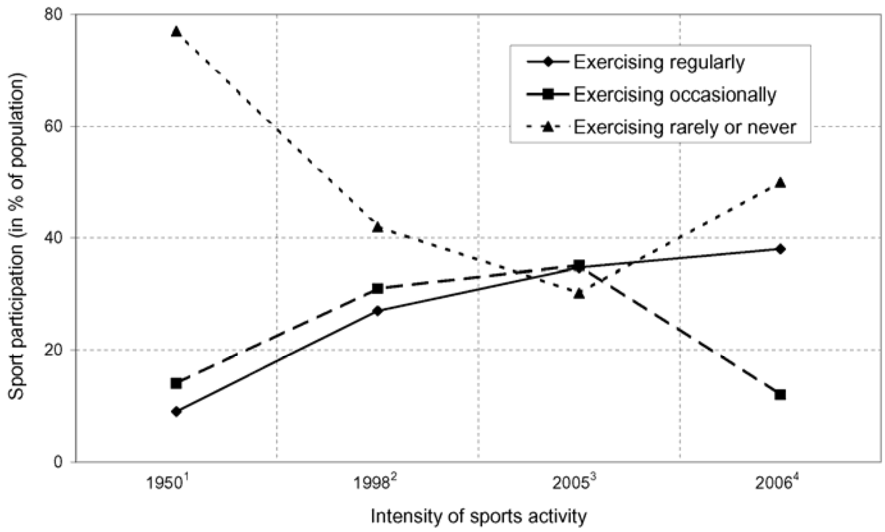



*Figure 2-1: Sport participation rates of the German population according to different social studies [1,2,3](Nagel, 2003, p. 65; Schwier, 2003, p. 18f.; Opaschowski, 200, pp. 61ff; Rittner, 1998), [4](Wasmer & Haarmann, 2006). The contrary drift of the participation rates in the latest evaluation is a multidimensional social effect which, among other reasons, can be explained by the drift of social states (see text).*

slightly according to different sources, the general trend is consistent. Despite finding an overall increasing number of relatively active people, Opaschowski discussed the tendency for a portion of the population, ranging between 25 % and 49 %, to be relatively resistant against sports activities (Hintemann, 2007, p. 54; Opaschowski, 2000, p. 67).

Another reason for the growing importance of sport is the fact that today many activities are being regarded as sport that would have been termed “extreme” or “work” just two generations earlier. Examples include climbing and cycling. Furthermore, aspects such as health, wellbeing, self-experience, self-expression and risk-seeking have been included in the perception of sport in addition to the traditional values of strengthening and competition.

Pluralization of sports culture:

The general sport environment has expanded substantially within the last 30 years. Today, sport is performed in a wider variety of locations and organizational structures. While only a few decades ago sport was confined almost exclusively to sports gymnasiums and playing fields, today sport has expanded to include public spaces and natural venues. The barriers of the sports club are broken, and public spaces and natural venues provide more space for freedom, a greater variety of locations and a very specific virulence and atmosphere (Bette, 1999).

More recently introduced sports, such as inline skating, triathlon, mountain biking, and climbing, represent types of activity that depart from established attitudes and reorganize institutional structures. In fact, the most impressive changes have occurred in the area of outdoor sports both in urban areas and in nature. The market of outdoor sports technology increased by 14.3 % in the period from 2003 to 2007 (Weck, 2009, p. 40), while the overall market for sports technology decreased slightly over the same period (Weck, 2009, p. 12). Some of the most popular trend sports established over the past several decades were outdoor sports that required a considerable input from sports technology, e.g. skiing, mountain biking, climbing, skating, freeriding[1] or walking.

More recently established sports that emphasize the role of the individual are often characterized by informal modes of organization. This means that sport communities evolve incidentally as so-called ad-hoc communities, and affiliation is continually redefined by current movements, equipment, fashion and music. Generally, the philosophy of the sport is not centered on performance, but lies in the loyalty to the motion and style of the sport (Gebauer et al., 2004, p. 15). More market oriented studies draw a similar picture of the changing organizational structures. A study by Hintemann showed that there has been a general shift from larger team sports to smaller, “situational” sport groups with flexible structures (Hintemann, 2007, p. 17). In addition, Vossen asserts that traditional structures and institutions of sport are

[1] Either refers to skiing off-piste or cycling on prepared parcours or natural trails involving a certain level of artistic elements.

deliberately ignored, especially by movements influenced by the youth-culture, and the focus is put on smaller, self-constituting groups (Vossen, 2005, p. 5).

Normality of sports engagements:

The macroscopic trends observed in sport parallel the transfer of sports activity to many facets of everyday life, and lead to an unobstructed view on sports engagements. This means that objects and activities that were formerly used in a different sense are now considered for or as sport. These include not only the bicycle as a training device and cycling as sport, but also sports shoes worn at the office for the acceptance and demonstration of sportiness. Today, sport penetrates all social spheres by combining many different lifestyles. For instance, elements of sports apparel such as sweatshirts, sports shoes and sports pants, have become pervasive in daily life and have gained importance for specific activities (Schmidt, 2002; Hintemann, 2007, p. 17). While climbing was formerly associated with adventurous undertakings in scaling large walls and reserved to an elite circle of sportsmen, today different types of climbing activities such as bouldering (climbing on boulders) are largely practiced as leisure sport.

Individualization of sports engagements:

A general tendency towards the individualization of sports engagements has recently been observed. According to Hintemann (2007, pp. 87f.), the pursuit of informal sports communities leads to an ongoing disintegration of the traditional comprehension of sport as physical strengthening and competition within the regulated unity of sports clubs. Motion patterns and regulations now depend on the participants and are equally formed by the protagonists, while in the so-called traditional sports the players are regulated by codified rules (Gebauer et al., 2004, p. 15). Recently established sports constitute themselves through social change processes where the body is the center point of interest and sport has become a stage-like performance (Gebauer et al., 2004, p. 10ff.). The attractiveness of sports activity is formed by motion patterns which reveal importance in the life of the protagonists through presentation and realization of style (Gebauer et al., 2004, p. 12).

### 2.1.3 Socio-cultural processes and their effect on sport

The socio-demographic and socio-cultural structure of people participating in sport is an important factor in understanding the motivational background for exercising sport. Youth culture driven sports such as skateboarding focus on different aspects of sporting activity than sports more predominantly associated with older generations such as Nordic Walking[2]. Figure 2-2 illustrates sports participation of Germans depending on age. Although the statistics vary considerably, the figure indicates that

[2] People exercising “Walking” tend to be at least 30 years old, with the majority being 40 years of age or older (Schäufle, 2009).

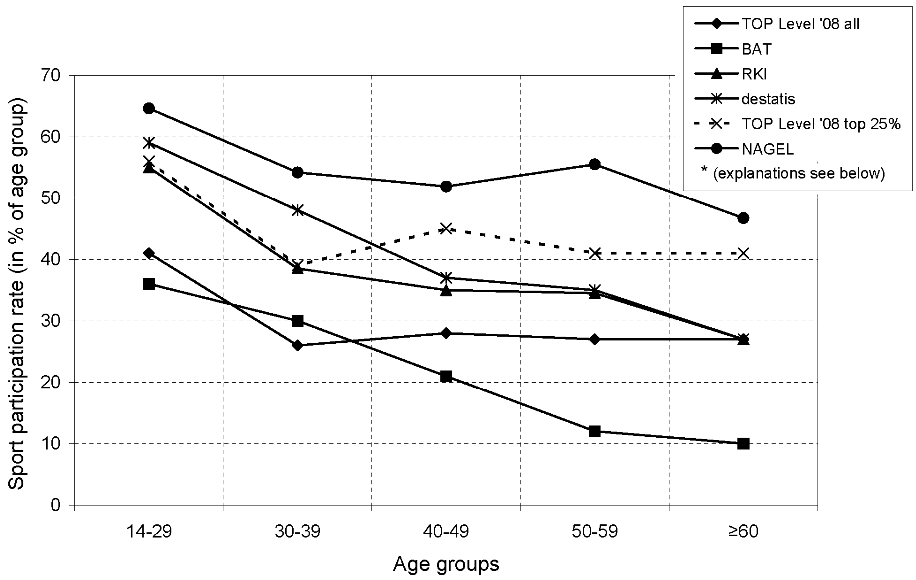



*Figure 2-2: Sport participation rates of the German population. The rates decrease considerably beginning at approximately 30 years of age (according to Abalin & Süsslin, 2008; Opaschowski, 2002; Mensink, 2003; Wasmer & Haarmann, 2006; Nagel, 2003)*[3].

participation in sport generally decreases with age. A large decline in sport participation can be observed in the group of 30–39 year-old Germans. This decrease is often associated with individuals accelerating their work force and starting a family which restricts the time available for sport.

Information on the social environments or background is necessary for understanding the motivational background of athletes. Perception of the so-called 'leadership groups', that are often part of the upper class, is of great importance when analyzing innovations in sports technology. The leadership character of these people implies that they are willing to pay higher prices for newly manufactured premium products to maintain their cutting edge status (Abali & Süsslin, 2008). As such, these people can help introduce new trends and technologies into the market. The 'leadership groups' are often seen as role models and are thus observed closely and appeal to many other groups of people, especially to the middle class (Hintemann 2007, p. 93; Flaig 2007; Schulze 1990, p. 419; Schulze 1992).

[3] Data base TOP Level: survey among the German population in 2008. 18-64 years. N=4195. People exercising regularly.

Data base BAT Freizeit Forschungsinstitut: survey among the German population in 2002. 14 years and older. N=3000. People exercise one or more times a week.

Data base Robert-Koch-Institut (RKI): telephone health survey among the German population in 2003. 18 years and older. People exercising two or more hours a week.

Data base Statistisches Bundesamt (destatis): Allbus 2004. Part of the German population exercising one or more times a week.

Similarly, Abalin and Süsslin present social habits of the “top25” of the German society[4], and the results revealed a direct link between a superior social status and sport affinity (see Figure 2-2). Approximately 68 % of the “top25” are interested or very interested in high-quality sports technology and approximately 50 % are willing to pay a higher price for excellent quality (Abali & Süsslin, 2008). Interestigly, new sport environments arise in the traditional middle class (16 % of the German population, 10.2 Mio. people). Gebauer et al. (2004, pp. 87ff) refers to this circumstance as “the bubbling petite bourgeoisie”. This does not, however, indicate that the influence of social status on the extent of participating in sport becomes less important. In fact, the results suggest that the social classes can be characterized by the extent of sport participation rather than by the preference to certain sports (Nagel, 2003, p. 29; Kreckel, 1992, p. 17). More detailed information can be found in the survey “Typologie der Wünsche” (topology of aspiration) in which specific socio-demographic characteristics of the approximately 22 million fitness-oriented people[5] in Germany were compared to the average world population (Typologie der Wünsche, 2002).

### 2.1.4 The change of motion patterns in sport

In addition to the general expansion of leisure sports, specifically outdoor sports, new motion patterns in sport have evolved. The so-called trend sports follow a reformation and innovation of the culture of human motion (Schwier, 2003, p. 18). Although these “new” motion patterns (roller skating or similar leisure sports were performed already in the early 20th century) were frequently novel, they were quickly adopted by larger groups of athletes (Breuer & Michels, 2003). For instance, the age group comprised of people “above 50” is increasingly involved in sports such as climbing, mountain biking or inline skating which formerly exclusively attracted people under the age of 20 years.

Schwier described three of the most striking changes in motion patterns. First, one of the most notable changes in the motion in sports is a trend towards increased acceleration. For example, the aforementioned outdoor sports are characterized by an increase in pace. Compared to traditional sports, outdoor activities appear agitating because the increase in pace is often combined with vertigo that may create mental states similar to trance (Schwier, 2003, p. 24ff). Another change in motion patterns relates to the accentuation of the perfection of human motion. In this sense, the

[4] German population between 18 and 64 years that is assigned to the top 25% of society, i.e. around 13 Mio. people. The group is differentiated by an index calculated by the status of education, income, career and background.

[5] Specification of target group: people exercising sport intensively for a minimum of two times a week. People who answered with a rank of 5 or 6 (on a scale from 1 to 6) to the questions “I try to keep myself fit by exercising sport” and “I find it important to do something for my physical and mental wellbeing” (Typologie der Wünsche, 2002).

importance of creative examination of motion tasks is emphasized compared to the traditional ideas of performance display and competition. Stranger stated that the “aestheticization plays also a pivotal role in providing an environment in which autotelic activities can be considered meaningful – free from the need for rational justification.” (Stranger, 1999, p. 274). Finally, the emphasis on the extreme is obvious in some sports. Extreme in this context refers to the ambition to test or exceed the body’s limits. This can take place at all skill levels because the concept aims at individual limits of an athlete rather than at absolute records. The appeal of extreme sports have been triggered and fortified by new sports technology. In mountain biking, for instance, the introduction of full suspension bicycles and disc brakes enhanced extreme downhill riding (Trillitzsch, 2001). The desire for adventures of self-experience lead to “thrilling fields” of sports (Hartmann, 1996).

It was suggested that sports technology today can be regarded as an extension of the human body used to enhance motion perfection and serve as a stimulation of emotions such as pleasure, tension and thrill (Gehlen, 1993; Gebauer et al., 2004, pp. 69ff). Sports technology enables athletes to carry out new characteristic motion patterns. The fusion of the human body and sports technology is integral to these sports, in contrast to traditional sports where equipment was viewed as the “opponent” (for example, the high bar in gymnastics).

### 2.1.5 Conclusions for sports technology design

The aspects discussed above are critical and relevant to sports technology. Despite similarities between traditional and more recently established sports in terms of the process of industrial realization, the latter show differences in several important ways. The evolution of sport has a direct impact on the range of opportunities for sports technology, as depicted simplistically in Figure 2-3.

Social context:

Social context refers to the social structure in which sports activities are performed. Despite the fact that organized sports, especially soccer, continue to play an important role in society, organized team sports practiced in sports clubs have become less common. In contrast, individual sports practiced independently or in ad-hoc communities is gaining popularity. Steady coaching of proper motor learning and training principles is rarely provided for newly established sports. This lack of guidelines and principles can be a source of innovation for sports technology. Measurement and information technologies can be combined with specific knowledge about the sport to generate objective learning and training systems (Vossen, 2005). Ideally, these systems could complement basic courses provided by professional instructors with digital advices to facilitate and support self-learning processes. Further, these systems could provide a platform for realizing specific sport motives (Hintemann, 2007, p. 87). The group of people aged 30–60 years accounts for approximately 44% of the overall population, or 36 million people, and is the largest age group in Germany. This is especially interesting because a majority of the economically important leadership groups, discussed above, fall within this age range. This age group influences and directs their children regarding sports activity, and is willing to invest more money to maintain a certain level of fitness despite a lack of free time. In addition, the group of people aged >50 years is increasing because of demographic shifts. Hence, sports technology, which serves the specific needs of these user groups, is presented with a growing market. Training support and advice that enable faster learning and/or safer exercising are examples of areas with considerable potential for market success.

Environment:

The dimension environment describes the venues were sports activities take place. Spaces for practicing sport are changing in line with social context. Most traditional sports have a fixed set of rules that limit the venue to sports halls and sports fields, the variety of motion patterns, or a combination of both. Many individual sports are performed outdoors, recapturing undefined urban or natural spaces. The recent increase in outdoor sports is an indicator for this tendency. Outdoor sports are typically equipment intensive and therefore have a bearing on the potential for the creation of new sports technology.

Motion:

The motion dimension incorporates the range and characteristics of motion patterns in sport. Recently established sports, especially outdoor sports, are seldom institutionally limited but rather assigned to the creativity of the participants themselves. In other words, the degrees of freedom are expanded and frequently accompanied by a trend to higher velocity in motion and a general increase of thrilling elements. Sports technology is used synergistically with the athletes and acts as an extension of the body. Sports technology must account for these trends and finds an open, largely unregulated field of possible applications.

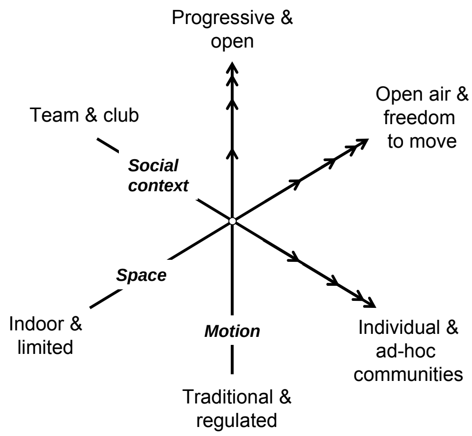



*Figure 2-3: Major trends in sport. The figure illustrates effects on the design of sports technology.*

## 2.2 The nature of Sports Technology

The findings of the preceding sections serve to form a socio-cultural environment into which sports technology design is embedded today. This section addresses the nature of sports technology itself and contains considerations on the general understanding of the term sports technology and gives a definition for the use in this thesis.

### 2.2.1 On the meaning of sports technology

| *Term description* |
|---|
| **Function**<br>A function is a purpose oriented, solution-neutral relationship between input and output parameters described as an operation (Ponn & Lindemann, 2008). |
| **Functionality**<br>Functionality is the ability of a system or subsystem to solve tasks. Systems of subsystems imply a functionality which is represented by one or a number of functions (own description). |
| **Product features**<br>Product features comprise all tangible and intangible values of a piece of sports technology, e.g. functionality, optics, image, etc. (own descirption). |

The terminology regarding technological objects for the purpose of facilitating or enhancing sport is inconsistent. This thesis uses the term “sports technology” as a synonym for technical objects as used for sport. Different from the more commonly used term “sports equipment”, the concept of sports technology encompasses the complete range of objects which have a technological basis. Ebert has elaborated about the socio-technological background of the term (Ebert, 2010, p. 21ff). He follows the definitions of Heinemann who describes sports technology as a socio-economical construct (Heinemann, 2000). Tinz provided a description of the term sports equipment in the context of lead-user analysis and points out the importance of functional components (Tinz, 2007, p. 162). Apart from the definitions presented by these authors, no other scientifically discussed definitions were found. In the present context, the term ‘sports technology’ is uniquely used in the sense of products. Basic questions to understand the nature of such products are: why do we generally use sports technology? What are the purposes of sports technology? Some indicators provide an initial response:

- Sports technology is equipment needed to participate in a particular sport.
- Sports technology is any object used for sport or exercise.
- Sports technology is equipment required for engaging in a sport and devices for the protection of athletes in exercising.

In fact, there are both obvious and more obscure reasons for using sports technology. In competitive sports, technical issues that affect the success of an athlete are a predominant design consideration. In leisure sports, on the other hand, other aspects such as optics or shape may play a role as well. The functional aspect in the sense of “purpose-oriented”, however, is a core component. In this work, we call these overall aspects product features. A functional product serves all functions the product was intended to achieve. In the context of engineering design, a function is defined as process-oriented (according to Ponn & Lindemann, 2008, p. 56). According to this definition, functions are concretized in technical realizations of tasks, changing input parameters in a predefined way into output parameters (see term description box).

The term “technical” is important because it specifies that color and shape, for instance, are not functional aspects of a product because there is no input and output with a given operation. In alpine skiing, a function can be an operation that allows a skier to perform turns (Figure 2-4).

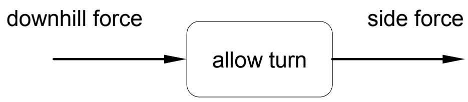



*Figure 2-4: Definition of a function that allows performing turns with alpine skis.*

The technical realization of the function manifests in the edges of a ski, carving into the snow during a turn and thus producing the appropriate side force to satisfy physical principles of a ski turn. Hence, functionality is defined by its underlying functions. Ebert provides a suitable concept for assessing functionality of sports technology and states that functionality is the entity of concrete realization of functions in a technical artifact (Ebert, 2010, pp. 28ff). In the present work, sports technology is used as a synonym for equipment that serves one or more of the following basic purposes (basic functions). The purposes are strongly related to the interface between the athlete and the technical object.

1. Enable the sport, i.e. facilitate performance:
   A sport cannot be performed without the specific piece of sports equipment (e.g. a ski is essential for skiing). This reason can be considered the fundamental purpose which will lead to a specific primary function of a piece of sports equipment.
2. Increase performance:
   A special feature of a piece of sports technology or the sports technology itself is designed in a way to help increase the performance of the athlete (e.g. special edge shape on a racing ski to increase grip, heart-rate monitor to control training). This always implies a proper interaction between the athlete and the sports equipment and ideally is based on individualized parameters (e.g. ski-length corresponding to body weight, personal fitness parameters).

3. Increase safety:
   A feature of the piece of sports technology or the sports technology itself is designed to increase the safety of performing a certain sport by using this piece of sports technology. This also implies safety against long-term injuries.

Following the function-oriented approach, sports technology is defined as a combination of the abovementioned aspects (see term description box).

| *Term description* |
|---|
| **Sports technology**<br>Sports technology are functional products that generally enable sports (allow performance), enhance the performance of an athlete or increase safety while exercising sports. |

### 2.2.2 Landscape of Sports Technology

Once sports technology has been defined as a concept, the specific field of interest must be separated from other areas of sports products. In the broadest sense, the sports market is segmented into the main product groups including sportswear, footwear and sports equipment (Vossen, 2005, p. 52). In this thesis, footwear (climbing shoes, running shoes, etc.) and sportswear (jackets, pants, underwear, etc.) are regarded as sports technology (Figure 2-5).

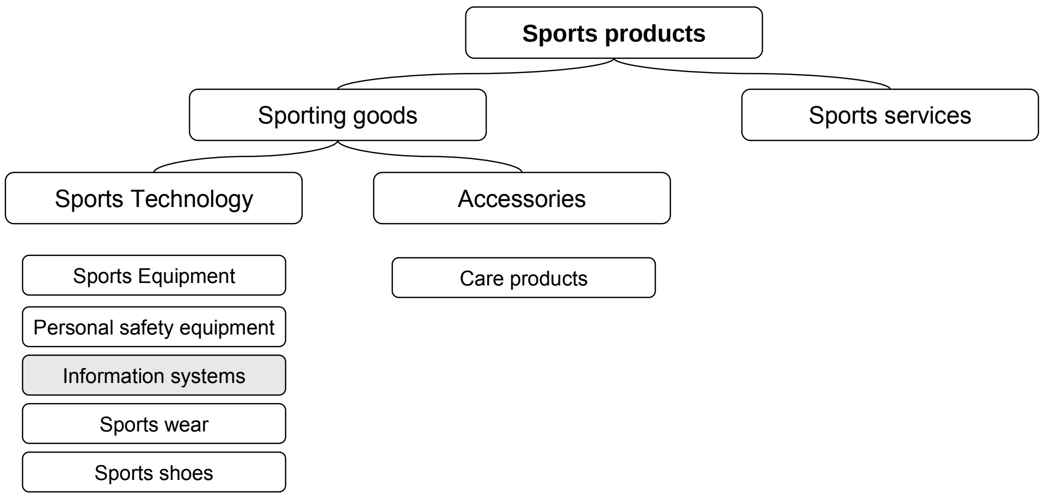



*Figure 2-5: Classification of sporting goods and embedment of the term "sports technology" (translated from Ebert, 2010). The application example in this work refers to the design of an information system for skiing.*

The field of sports technology also includes sports equipment (skis, bicycles, inline-skates, bars, etc.), personal safety equipment (helmets, back protectors, knee protectors, glasses, etc.), and sports information systems (all electronic devices that provide additional information on vital-, performance-, or training-parameters or other information or electronic systems used for sports purposes). This segmentation follows Ebert's classification (Ebert, 2010, p. 25).

A sporting good is any object used for the purpose of sports while sports technology is equipment that has a functional component with the goal to support sports activity in the previously defined manner. Sports equipment includes objects that are essential for carrying out a certain sport. In a wider sense, this can also include sports facilities. Footwear is equipment worn on an athlete's foot to facilitate or enhance his capabilities in a particular sport. Sportswear is any covering designed to be worn on a person's body with the purpose to functionally protect or cover the person against environmental influences while exercising sport. Safety equipment is equipment applied to a piece of sports equipment or worn by a person and specifically designed to increase safety and provide protection while exercising sport. Information systems provide information on vital-, performance-, or training-parameters either while exercising or later for analysis (see Figure 2-5). Accessories are products such as personal care products (crèmes, cleaning solutions), bags for MP3 players and similar products. Sports services are services that are provided in the context of sports. Examples of sports services include instruction and event management.

### 2.2.3 Landscape of Sport

In the preceding sections, multi-dimensional aspects of sport and sports technology were presented. A classification of these aspects follows the background information and aims to incorporate and relate participants of the world of sport to each other, and place them into specific thematic contexts. The classification specifies to which thematic fields the present research is attached. Figure 2-6 depicts these coherences and the fields of research of this thesis. The landscape of sport is explained as follows.

The core:

The core of sport consists of specific rules, motion patterns, techniques, and the range of different sport modes and sport types. A common classification distinguishes the following sports modes: athletics (e.g. running, high-jumping), roll-sports (e.g. cycling, inline-skating), gliding sports (e.g. skiing, short-track), ball-sports (e.g. soccer, basketball), dance sports (e.g. rock'n'roll, break-dance), combative sports (e.g. boxing, karate), water-sports (e.g. swimming, surfing), air-sports (e.g. paragliding), acrobatics and gymnastic, mountaineering, climbing and fitness and strength sports. Sport can also be divided into types of sports emphasizing endurance, strength, coordination, or team or individual aspects. Sport contexts can be defined by a focus on recreation, leisure, performance, competition, or education.

This thesis concentrates on leisurely exercised gliding sports (skiing and mountain biking).

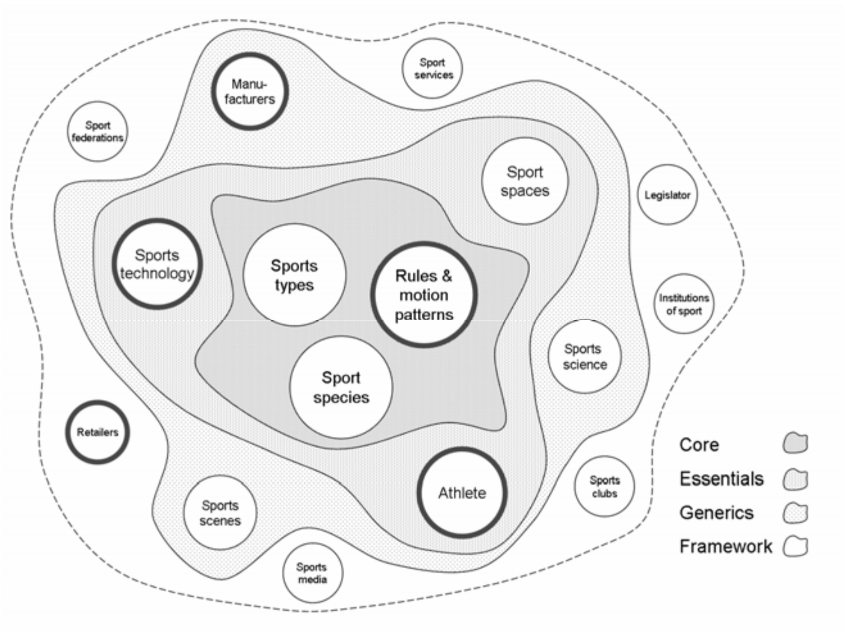



*Figure 2-6: Landscape of sport with constitutional elements. The focus of research is highlighted.*

The essentials:

The "essentials" are formed by the elements that are required to exercise and perform sport. These include the athlete himself, sports technology (e.g. sports wear, skis), and any space or environment were sport can be carried out (e.g. fitness-studios, slopes, freeride-parks). The athletes' motivational background and its effects on the use of sports technology are highlighted in this thesis. The different sport environments are not covered explicitly, although they influence the design of sports technology as sources of boundary conditions (e.g. in terms of environmental impacts such as ground reaction forces).

The generics:

This level contains elements that contribute to the realization of sport in the sense of the "core" of sport and the "essentials". Sport scenes here are groups of protagonists of a certain sport. Scenes are hybrid constructs which are formed by people actively involved in a certain sport and can be regarded as constitutive instances and representatives of a particular sport. Sports technology manufacturers in a wider sense are regarded as the producers of all movable goods and immobile objects necessary for sport. Sports science is involved in research of proper training techniques, sport psychology, sport sociology, sport medicine, sport philosophy, biomechanics, sport informatics, sport media, sport economics and sport history (Röthig et al., 2003, pp. 555ff). In this thesis, investigations addressing the viewpoints of sports science and sports technology manufacturers are carried out with respect to motivational implications in sport and important product features.

The framework:

The framework describes factors providing the social, organizational, institutional, media or economical frame of sport. These can be the group of people in a society that generally participate in sports, sports federations (e.g. the international federation of skiing), institutions of sport (such as training centers for competitive sports, sport in schools, etc.), the legislator (in terms of laws affecting sport, e.g. the obligation to use helmets), sports media (e.g. press, television), sports clubs, sport services (e.g. ski-schools, event-management, etc.) and retailers (who account for the distribution of sporting goods). Sports retailers are the market-oriented, direct link between manufacturers and athletes. Their knowledge about the product and athlete-oriented mechanisms in sport are used to highlight opportunities and challenges in sport in addition to the viewpoints of manufacturers and the athletes themselves.

## 2.3 A scientific view on sports technology

Because the field of investigations in sports technology design is characterized by contributions from various disciplines, a survey may serve to clarify state-of-the-art in these disciplines and synthesize knowledge from former research projects.

### 2.3.1 Study design, materials and methods

The preliminary exploratory study presented here is based on the idea that expert knowledge from different scopes of research could be merged to find the most important aspects and deficiencies with respect to sports technology design.

A conjoint workshop, in which an open discussion about a specific topic takes place, was regarded as problematic because of the still unstructured field of discussion points. Instead, a modification of the Delphi method was used to combine the knowledge of different experts (Müller et al., 2007; Boehm, 1994). The modified Delphi method can be considered an appropriate method for information procurement through a structured multi-inquiry of experts (Linstone, 1978; Ono, 1994). For this study, two questionnaires were prepared for and completed by a group of experts. The results of the questionnaires were then discussed in two group meetings. A list of statements was prepared based on information obtained from literature research, analysis of former design projects and brainstorming. This list was used in the preparation of the initial questionnaire that was presented to the group of experts before the first group meeting (Table 2-3). The focus topics of the questionnaire were related to the design of sports technology for leisure sports and aimed at the importance or the degree to which an item applies to a specific sport. The full outline of the questionnaires is given in the Appendix 8.1.2 and 8.1.3. A minimum of two questions were formulated for each question complex. All questions were arranged in random order. A four-step rating scale ranging from 'very important' (4) to 'not relevant' (1) was used. The following experts participated in the study: Prof. Kristina Shea, Prof. Veit Senner, Prof. Jürgen Beckmann, Dr. Harald Böhm, Dr. Peter Spitzenpfeil, Matthias Blümel, Christoph Ebert, Prof. Michael Krohn, and Dr. Fozzy Moritz. Table 2-2 depicts basic information on the sample group.

*Table 2-2: Sample and fields of experts' expertise*

| *Sample group parameter* | *Specification* |
|---|---|
| Size and respondents | N = n = 9 |
| Fields of experts' expertise | Product development<br>Biomechanics<br>Sports psychology<br>Computer modelling<br>Exercise diagnostics<br>Sports technology<br>Teaching in sport<br>Interaction design<br>Innovation reserach |

## 2.3.2 Execution and data analysis

The first group meeting was held on November 13th, 2006, and the second group meeting was held on May 23rd, 2007. The questionnaires were filled out anonymously by the experts before each of the group meetings. The group meetings were video-taped, and the experts' core statements were extracted from the video tapes. The results of the questionnaires were evaluated statistically and qualitatively where necessary.

*Table 2-3: Initial question complexes for the first questionnaire of the expert survey*

| Topic | Question complex | Query no. |
|---|---|---|
| Sport motives | Fun is a driving motive | 3.2, 3.3, 3.5 |
| | Sports equipment as auxiliary of prevention against harm | 3.12 |
| | Sports equipment as means of rehabilitation after desease or surgery | 3.32 |
| | Psychological addiction due to the generation of special thrills | 5.7, 5.1 |
| | Direct relation of performance display/physiological gross efficiency | 5.1, 5.8 |
| | Motor activity as a challenge | 5.6, 5.12 |
| | Sports equipment to improve personal performance | 5.9, 5.11 |
| | Socialication effect of sport equipment through group specific design | 3.17, 3.21, 3.18 |
| | Sports equipment as means of compensation of office work | 3.4 |
| Product features | Approaches for leightweight structures | 3.1 |
| | High market impact of successful competition equipment | 4.1 |
| | Highly dynamic loading cases | 3.27 |
| | Intensity of response from equipment | 4.5 |
| | Adaption to antropometry (kinematics-antropometry) | 5.13, 5.14 |
| | Individualization effect of sports equipment | 3.23, 3.24, 3.31 |
| | Mass customization is a prior goal | 4.3 |
| | Optimization of ergonomy (kinematics/ease of handling - ergonomy) | 5.2, 5.3 |
| | Effect of safety equipment is taken into account/accidents are expected | 3.6, 3.11, 3.29 |
| | Tolerated fails of specifications by the user | 4.4 |
| | Impact of trend sports on consumer behaviour | 3.9 |
| | Impact of sports trends on consumer behaviour | 3.19 |
| | Impact of design on trends | 3.15 |
| | Importance of design besides functional requirements | 5.4, 5.5 |
| | Field of mechatronic accessoires as a special attraction | 3.28, 3.13 |

### 2.3.3 Results

The results of the first questionnaire are summarized with regards to specific focus topics as depicted in Figure 2-7. The second questionnaire contained open questions which were categorized for analysis.

The topics shown in Figure 2-7 are further defined as follows. Sport motives refer to possible reasons for people to engage in exercising sport. Product features specify topics of interest for the technical and visual design of sports technology. The topic individual inventiveness refers to the possibility of inventions in sports technology driven by individuals or a group of enthusiasts. Response behavior equipment concerns the mechanical feedback from a piece of sports technology received during sports activity. The topic safety and risk-taking refers to the importance of product safety for the degree of acceptance by the user. Mechatronic accessories refer to the potential of electronics and/or information technologies. It should be mentioned that the statements were reproduced in their original form. Frequently used terms such as "sports equipment" in these statements often refer to the term "sports technology" as it has been defined in this thesis. In the following, the core statements will be presented, followed by a brief discussion.

According to the results of the questionnaire, the most important sport motive was fun experience. During the first group meeting, fun was discussed as the main

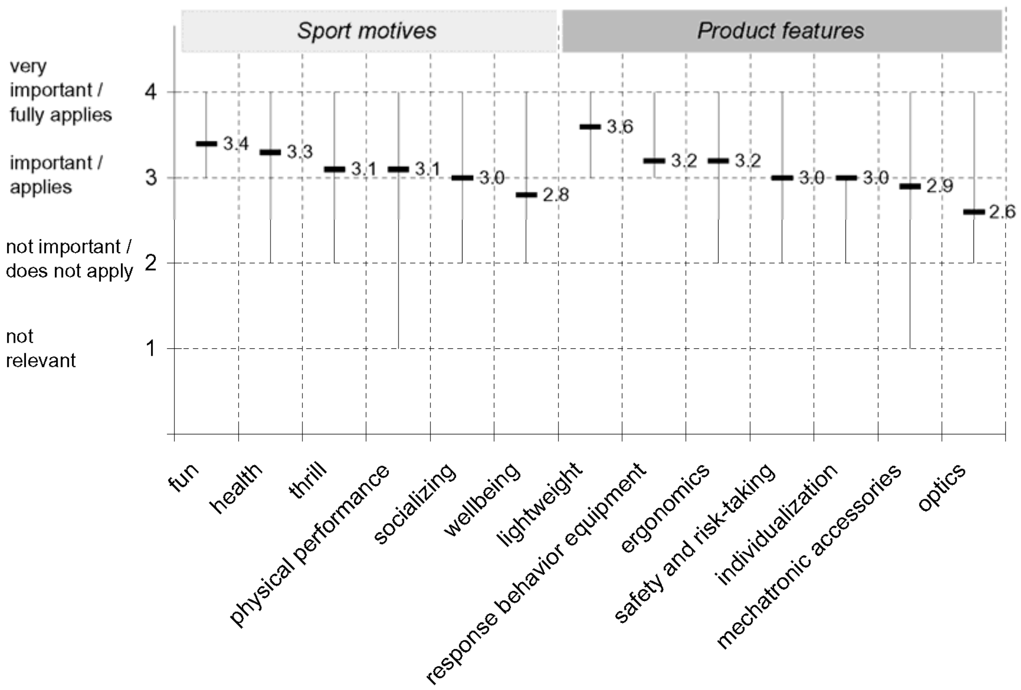



*Figure 2-7: Important aspects in sport technology with ratings (mean value and span) from experts.*

motivation for leisure sports with the other listed motives creating positive side effects. Therefore, the second group meeting focused on the connection of fun to different product related aspects. The following statements obtained during the second group meeting refer to the role of fun.

- “One purpose of sports technology can be to facilitate more “sense” of fun. For instance, learning to ski is easier with carving skis.”
- “Sports equipment can make sports more fun for less skilled people, for example with beginner shaped skis, and high end equipment can make sports more fun for highly skilled people, for instance for deep powder skiing.”
- “Technology itself can be fascinating and a reason for fun.”
- “Fun is the source of sports activity. Fun oriented sports equipment does allow the user many degrees of freedom (skateboard).”
- “Mountain bike suspensions, for example, have enabled a much higher state of comfort for a higher downhill speed. Such aspects also contribute to the experience of fun.”
- “Equipment should support the mastering of motion tasks and at the same time provide a source for basic safety needs (moderate anxiety as the opponent of curiosity).”

- "Risk can be a source of fun. It is especially the mastering of the risks which motivates. Equipment extends our capacities for mastering the challenges."
- "People only looking for leisurely fun want their sports equipment to protect them against injury and reduce the risk of injuries while extreme sports enthusiasts derive fun from the substantial risks involved in the sport."
- "Motivation through fun is very important. But it's a difficult task to measure the different facets of fun with relation to sports equipment. For example, what is it that we call fun? What are the reasons why we use sports equipment? A product has to be emotionally and functionally "good" to be accepted in the long term."
- "Perhaps a new test philosophy should be established, somehow a mixture between methods from social science and engineering. We must start from the subjective viewpoint and approach to objective measures."

The following statements obtained during second group meeting refer to the evaluation of product features. A major discussion point was the importance of safety in relation to sports technology.

- "Risk is accepted in motion; sports equipment should be totally safe."
- "The sensation of risk and safety is very personal. Generally risk is taken into account to some extent to improve skills in a certain sport."
- "There is a general lack of safety standards in all fields of sport."
- "Unsafe situations are accepted to a certain extent. But the risk of injuries is being tried to avoid by protection equipment."
- "Personal safety equipment is often uncomfortable and therefore not accepted."
- "There is too less information provided about the risks of using a certain piece of equipment. For example, for elderly people it should be taken into account that they should not be exposed to high loads and full motion ranges."
- "Optics or style elements often mask product functionality."
- "Frequently, so-called product innovations concentrate on the marketing."
- "Very few valid testing and evaluation methods are available for the different aspects of functionality. For instance, lightweight design is not based on proper assumptions so far. A model should be established that facilitates the estimation and importance of different aspects, perhaps even based on a computer model in the first place."
- "There is a lot of knowledge in biomechanics about the interaction of human and environment. It should be used more intensely for the purpose of individualization and ergonomics with respect to sports technology."

- “You could imagine sports equipment that has integrated measurement devices, such that one could see if the loads or the durability are exhausted.”
- “The problem is always about measuring things. More effort has to be put into the development of measurement technology that enables free motion and less hampering during the sports activity. A good interaction of equipment and the user is needed.”

### 2.3.4 Discussion

Despite the large variety of different aspects initially addressed in the questionnaires, some basic conclusions can be drawn. The emotional attachment of people to sports equipment appears to be mainly based on motion experience and the interaction of the athlete and sports technology. In particular, a construct termed “fun experience” seems to be the driving force for most leisure sports activities across all user groups. The comprehension of this construct, both in terms of its differentiation and determination, is largely intangible in connection with the use of sports technology. A new test philosophy was proposed that could begin with subjective viewpoints of the users and further integrate variables to ultimately determine technical design. The attraction of sports technology can lay in aesthetics, motion challenge, and facilitation of motion or thrill through motion.

The relationship between risk and safety is an important aspect not only with respect to the potential risk of a certain motion, but also with respect to sports technology. In general, people are willing to accept a certain degree of risk in exchange for improvement in their skills or for enhancement of their experience. Sports technology itself should be subject to strict safety standards. A general lack of education of the potential risks when using particular sports technology is apparent. Therefore, the available knowledge from biomechanics could be used to transfer technology to the users in a more appropriate and profitable way. Safety and a variety of other product features (here: uniquely referring to functionality) need attention in terms of evaluating the underlying mechanisms a priori. Often though, testing methods and measurement technology which are suitable for application in leisure sports are not available. The source of measurement technologies could be used to improve functionality, although this has not yet been realized.

In summary, the results of this study identified three interdependent fields of interest that were regarded as characteristic for sports technology: the motivational background of the user and its effects on the use of sports technology; the biomechanical interaction of the athlete and sports technology in terms of motion tasks; and the product features of sports technology that account for the two aspects named before.

# 3 Sport motives and product features in a motion context


Three interdependent fields of interest were identified from the results of the preliminary study conducted to determine the most important aspects and deficiencies with respect to sports technology (Section 2.3). First, the results suggest that more thorough research into an athletes' motivational background should be conducted to focus the efforts of an objective evaluation for sports technology design. Second, the attractiveness of a piece of sports technology is defined by its functional, aesthetic, or otherwise valuable product features (Ebert, 2010, p. 31f), and design efforts should focus on meeting customers' explicit or implicit expectations. In this context, the functionality of a product should be regarded as part of its product features. Furthermore, the survey of experts showed that the implementation of measurement tasks regarding the previously discussed aspects and the interpretation of its outcomes is a recurring issue in research and design. Third, the explanation of motion and the interaction of an athlete with his environment can be a source of product novelties for the field of leisure sports. Motion context must be considered in sports technology design. In addition, opportunities of mechatronic systems in terms of motion support have been addressed as a possible source of innovation. Before research in these areas are initiated, their relative importance must be differentiated and specified. While the main focus of this thesis was the application of sports technology to the sport of skiing, the research also addressed sports technology for mountain biking. By

| *Term description* |
| --- |
| **Function**<br>Refers to basic functions and trouble free operation of sports technology. |
| **Ergonomics**<br>Refers to the adjustability of sports technology to the individual body form and anthropometry. |
| **Performance**<br>Refers to technical performance characteristics of sports technology like weight and stiffness. |
| **Optics**<br>Refers to colour and shape. |
| **Safety**<br>Refers to product design against failure and to safe use of the product. |
| **Mechatronic**<br>Interaction of mechanical and electronical parts of a system together with information technologies. |

extending the research to include mountain biking, the results were further validated, and additional areas for future research were identified. Some basic terms regarding product features that were used in conjunction with the surveys are defined in the term description box above. Three groups of people were identified and chosen for interviewing, as discussed below.

Sports technology manufacturers:

In an environment with very short product life spans (Weck, 2009, p. 11), new products featuring clear benefits to the customer are of utmost importance to sports technology manufacturers. New product designs are initiated by different triggers. Thus, sources and possible obstacles in the development of product novelties were subject of evaluation as well. The mantra “form follows function” (Sullivan 1896) is one of a number of possible principles in product design. The investigations in this thesis aim to determine the importance of different product features in product design. In addition, the goal is to determine factors that trigger design activities. To compare product related aspects to motivational aspects from the manufacturers’ viewpoint, the importance of the athlete having a fun experience while using sports technology needs to be evaluated. Finally, mechatronic sports technology can be a way to introduce completely new functionality to the sports market. It may, however, be subject to a variety of prerequisites. The goal is to identify potentials and prerequisites from the sports technology manufacturers’ point of view.

Sports retailers:

Sport retailers are directly in touch with the athletes (i.e. consumers). Therefore, it can be expected that their selling experience gives them greater insight into the sport motives of a large percentage of the population, allowing them to act as representatives for the people in regards to sports technology. In general, innovation can only be recognized by innovative products that sell successful. Thus, the sports retailers’ view on product novelties is considered important. The product features specified above cover important aspects of sports technology. The significance of these aspects from the viewpoint of selling and additional aspects of product features should be identified. With respect to characteristics of sports technology, it is useful to investigate important aspects from the sports retailers’ point of view. The opinions and insights of sports retailers may be considered an important source in finding potential application fields and prerequisites with regards to the use of mechatronic systems in sport.

Athletes:

Product design aims to meet consumers implicit or explicit needs. Therefore, the user’s perspective often reveals insight into their focus product features. In addition, to the view of sports technology manufacturers and sports retailers, the athlete’s self-reflection about sport motives was included in the survey and serves a particularly valuable function when there are inconsistencies in the views of manufacturers and retailers. Furthermore, athletes are the potential customers for innovative sport products. As such, it is important to identify objections, potentials and prerequisites for mechatronic system design.

The corresponding research questions were formulated as follows.

1. What are the motives of people for exercising sport?
2. Who are the main target groups of sports retailers? What are their characteristics and which group is focused on in the future?
3. What are the driving forces and obstacles for product novelties?
4. What is characteristic about sports technology?
5. How is the importance of specific product features valued in different contexts?
6. How is the market potential of mechatronic systems in sports technology valued in different contexts and which are important success factors?

## 3.1 Sports technology manufacturer view

*Term description*

**Sports technology manufacturer**

„A sports technology manufacturer is a company involved in research, design, production and marketing of sports technology .“

Sports technology manufacturers create sports technology, and hence are interested in the focus and realization of sports technology design. This chapter aims to evaluate the external validity of the findings from research experience and surveys conducted within the scientific field of sport. It clarifies whether the addressed challenges apply to a wider scope of industry representatives and whether there are additional problem fields which were not previously considered. Until now, insight into the practical design work of sports technology manufacturers was limited to selected research projects. The survey conducted as part of this thesis focuses on the research questions posed in the preceding section, and focuses on alpine ski and mountain bike manufacturers. The term sports technology manufacturer is defined in the term description box above.

### 3.1.1 Literature

Little information has been published referring to the design process of sports technology manufacturers. However, there is some information available regarding the role of product novelties which are important success indicators for companies. With regard to the sporting goods sector, Nielsen (1993) reported that only 2.2% of all introduced products are real innovations. More than 45% of all introduced products were identified as so-called “me-too” products, or products designed to be similar to another company's product already on the market, and the remaining products are optimization or evolutionary designs. According to Nielsen, another problem is that new designs in the sports sector often do not serve customers needs (Nielsen, 1993). Tinz provided some information on the role of functionality in the design of sports technology, as defined in the term descriptions at the beginning of this chapter. However, findings by Tinz focused on benefits and constraints of collaborations between users and sports technology manufacturers in design projects (Tinz, 2007), which is not a focus of this thesis. Krüger conducted a survey among sports technology manufacturers and identified external and internal sources that initiate new product design projects (Krüger, 2006). Some of the questions he posed were used as a basis for this thesis.

### 3.1.2 Study design, materials and methods

Basic information on the study design, measurement instrument, sample group and execution of the study are provided in this section.

The study was designed as an explorative, cross-sectional case study using an online questionnaire for collecting data. Because the addressed sports technology manufacturers are located throughout Germany, Europe and the United States, an in-person interview was not considered a viable method of investigation. Instead, the survey was conducted as a partly structured online questionnaire (Bortz, 2006, p. 238). By including several open questions, additional information on specific topics was obtained from the participants of the study. Under the guidance of and using the research questions and study outline provided by the author of this thesis, the survey was conducted by a fellow student (Segerer, 2008). The results of the survey were reprocessed for this thesis. Specific terms used in the online questionnaire and for the presentation of the results are explained in the term description box at the beginning of this chapter. The answer scale used for the closed questions on the survey was a four-step scale: "very important" (4), "important" (3), "not important" (2), and "not relevant" (1). To explore tendencies of the subject, the scale did not include a neutral category and utilized only a small number of ratings. The full outline of the online questionnaire can be found in the Appendix 8.2.1.

According to the definition by the Commission of the European Communities from May 6th, 2003, small- and medium-sized enterprises are enterprises with less than 250 employees and a maximum turnover of 50 million Euros. Information on the structure of sports technology manufacturers in regards to enterprises is shown in Table 3-1.

*Table 3-1: Size of sporting goods manufacturers regarding turnover (according to Hanna, 20061; Tinz, 20072; own data3)*

| *Turnover (in Mio. EUR)* | *Sporting goods manufacturers, Europe, n=887 (in %)[1]* | *Sports technology manufacturers, GER/AT/CH, n=62 (in %)[2]* | *Alpine ski manufacturers, Internat., n=7, (in %)[3]* | *Mountain bike manufacturers, GER, n=7, (in %)[3]* |
|---|---|---|---|---|
| < 10 | 82.3 | 48.4 | 14.3 | 42.9 |
| 10 - 49 | 14.4 | 28.9 | 21.0 | 42.9 |
| ≥ 50 | 3.2 | 25.8 | 57.1 | 14.3 |

As previously discussed, the alpine ski and the mountain bike sectors were considered in this study. The first step in the selection of a sample group for this study included generating a list of alpine ski and mountain bike manufacturers found through an internet search. Because turnover numbers were not readily available for most of the companies, the size of the current product category was used as an alternative measure to assess the size of the companies. Important figures about the sample group are provided in ■ Table 3-2. The representatives for the various companies that completed the survey were members of the development departments in leading positions, either as head of research and design, or head of the alpine ski or mountain bike departments.

■ *Table 3-2: Sample and size of the sports equipment manufacturers considered for the survey*

| | *Ski manufacturers* | *Mountain bike manufacturers* |
|---|---|---|
| Sample group | N = 18 | N = 29 |
| Respondents | n = 12 | n = 7 |
| Return rate | 66.7 % (of n) | 24.0 % (of n) |
| Number of product models | 6 - 73 | 4 - 196 |

### 3.1.3 Execution and data analysis

Prior to distribution of the online questionnaire via e-mail, the sample group representatives were contacted by telephone to determine their willingness to participate in the study. The representatives were provided with standardized information on the study. The questionnaire was made available online from January the 30th 2008 to July the 1st 2008.

### 3.1.4 Results

What are the apparent motives of people for exercising sports?

Both alpine ski and mountain bike manufacturers indicated that it is very important for users of their products to have a fun experience (Table 3-3).

*Table 3-3: Importance of enjoyable experience from the manufacturers' point of view*

| *Alpine ski, N=12, n=11 (very important: 1, not relevant: 4)* | *Type of motive* | *Mountain bike, N=8, n=8 (very important: 1, not relevant: 4))* |
|---|---|---|
| 3.9 | Fun experience | 3.7 |

What are the driving forces and obstacles for product novelties in sports technology?

The initial step in answering this question was to examine the degree of novelty of products as they relate to the results from the following section about driving forces and obstacles for product novelties. Only product design projects that were conducted in 2006 were considered. The degree of novelty, a subjective rating, was rated by the participants of the study. A new product concept was described as a concept that varies significantly from previous products. In terms of their functionality (e.g. regarding function, performance, etc.), optimizing designs were described as modifications to parts of the product or a redesign of a single component.

Overall, the ratings given by the alpine ski manufacturers and the mountain bike manufacturers were consistent (range: 1.7 %). Based on available information, approximately one-third of the products produced in 2006 were new products with substantial variations and improvements on older products, and two-thirds were design optimizations based on modifications or redesigns (Table 3-4).

*Table 3-4: Type of product novelties produced in 2006, rated by the sports technology manufacturer*

| *Alpine ski, N=12, n=11 (% of mentions)* | *Type of product novelty in 2006* | *Mountain bike, N=8, n=8 (% of mentions)* |
|---|---|---|
| 34.6 | New product, real innovation | 32.9 |
| 65.4 | Novelties based on optimization | 67.1 |

The survey results showed that spontaneous ideas formed within the companies are the most important driving force for mountain bike manufacturers and the second most important driving force for alpine ski manufacturers in the realization of product novelties (on the left of Table 3-5). Benchmarking also plays a very important role in market and product analysis. For alpine ski manufacturers, benchmarking was shown to be the most important source of ideas, while it was found to be the second most important source for mountain bike manufacturers. In addition, two related sources of ideas were independently identified multiple times by the manufacturers under the “others” category: market observation and trend analysis. Lead users, specifically professional athletes, and customers were also identified as contributing to the process of product novelty creation. Several other driving forces were identified and included factors that typically occur within the design centers such as company specific (own) tests, evolution and experience. In total, the “others” category accounts for approximately one third of new design ideas. Systematic idea generation methods play a minor role in new product idea generation and is applied 19.7 % of the time.

Regarding influences that hinder the realization of product novelties (on the right of Table 3-5), the human element is critical in three respects. First, human resources for product design appear to be severely limited in the companies that participated. For mountain bike manufacturers, 100 % of the product novelties were reported to be affected by constraints in the availability of human resources. Second, preventers of innovations, for whatever reason, were also named as a limiting factor. Third, missing internal competence in product design could be solved through cooperation with other companies or research institutes in one sixth of the cases.

Investment, which is indispensable for the realization of new product designs, was identified as the most important limiting factor by alpine ski manufacturers. In total, 58.4 % of all participants stated that investments represent a constraint for them. Also, elevated product costs were identified as a constraint under the “others” category. While marketing was not listed as a constraint by alpine ski manufacturers, half of the mountain bike manufacturers surveyed indicated that marketing is a problem when it comes to the introduction of new products. In a related sense, an already existing, wide product range was identified as a hindrance to the proposal and realization of new products.

*Table 3-5: Driving forces and obstacles for the realization of product novelties from the manufacturers' viewpoint*

| *Driving forces* | *(% of mentions)* | *Limiting factors* | *(% of mentions)* |
|---|---|---|---|
| Spontaneous ideas | 66.7<br>85.7 | Human resources | 50.0<br>100.0 |
| Benchmarking | 75.0<br>57.1 | Investments | 66.7<br>50.0 |
| Methods | 25.0<br>14.3 | Marketing | 0.0<br>50.0 |
| Others:<br>Market observation<br>Trend analysis<br>Own tests<br>Customer meetings<br>Evolution<br>Input from Professionals<br>Experience | 25.0<br>42.9 | Experience | 16.6<br>33.3 |
| | | Lack of methods | 16.6<br>33.3 |
| | | Legal restrictions | 0.0<br>33.3 |
| | | Lack of cooperation | 16.7<br>16.7 |
| | | Lack of ideas | 16.7<br>0.0 |
| ☐ Alpine ski manufacturers (n=12)<br>■ Mountain bike manufacturers (n=6) | | Others:<br>Product costs<br>Too many products<br>Defeatists | 33.3<br>50.0 |

Lack of experience and methods were identified as limiting factors by 25 % of the companies. Mountain bike manufacturers identified these topics as limiting factors in the realization of product novelties twice as often as alpine ski manufacturers. Mountain bike manufacturers did not report a lack of ideas as a hindrance in the realization of product novelties, while it was viewed as a minor problem for alpine ski manufacturers. Conversely, legal restrictions were only reported to be a limiting factor by mountain bike manufacturers, with approximately one third of the companies surveyed reporting constraints because of legal restrictions.

Which evaluation methods are used to support the design process of sports technology?

Results of the survey shown in Figure 3-1 describe the different evaluation methods used in the design process of sports technology by alpine ski and mountain bike manufacturers. Vertical and horizontal summaries were made with respect to evaluation methods given in the survey and for the product features, respectively. On average, the eight alpine ski manufacturers that responded to the questionnaire use

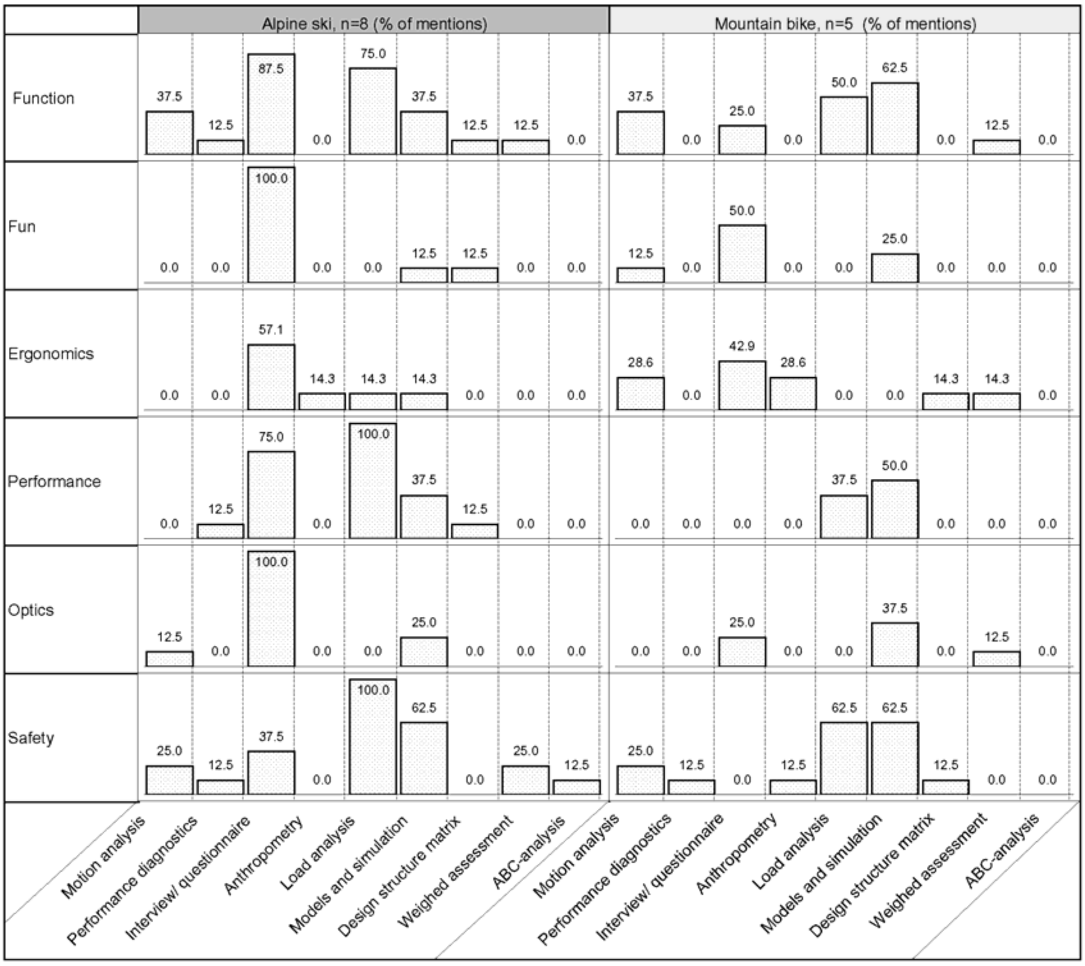



*Figure 3-1: Evaluation methods used for product design by sports technology manufacturers.*

evaluation methods more frequently (21.3 %) than the five mountain bike manufacturers (14.0 %). Interviews and questionnaires, load analysis, and model building and simulations are the most frequently applied evaluation methods used by both sectors (Table 3-6). Motion analysis is the only other evaluation method used to some extent.

The majority of the listed evaluation methods are applied to testing product function and safety. Alpine ski and mountain bike manufacturers use the listed methods in testing 30.6 % and 20.8 % of the time, respectively. Other product features were heterogeneously applied with respect to the use of evaluation methods. Alpine ski manufacturers use 26.4 % of the listed methods for evaluation of product performance, 15.3 % for optics, 13.9 % for fun, and 11.1 % for aspects of ergonomics. In contrast, mountain bike manufacturers use 14.3 % of the methods to evaluate aspects of ergonomics, 9.7 % to evaluate performance, and 8.3 % for the evaluation of a fun experience.

*Table 3-6: Average use of evaluation methods for design tasks*

| *Alpine ski, N=12, n=8 (% of mentions)* | *Evaluation method* | *Mountain bike, N=8, n=5 (% of mentions)* |
|---|---|---|
| 12.5 | Motion analysis | 17.3 |
| 6.3 | Performance diagnostics | 2.1 |
| 76.2 | Interview/ questionnaire | 23.8 |
| 2.4 | Anthropometry | 6.8 |
| 48.2 | Load analysis | 25.0 |
| 31.5 | Models and simulation | 39.6 |
| 6.3 | Design structure matrix | 4.5 |
| 6.3 | Weighed assessement | 6.5 |
| 2.1 | ABC-analysis | 0.0 |

How do sports technology manufacturers value the importance of specific product features?

A variety of topics were analyzed from the data of the online questionnaire. For reasons of visualization and clarification, the mean values were calculated. They are drawn for all items together with the maximum and minimum value as a measure for the overall answering trend and the maximum span of different opinions (presented as Δ values), respectively.

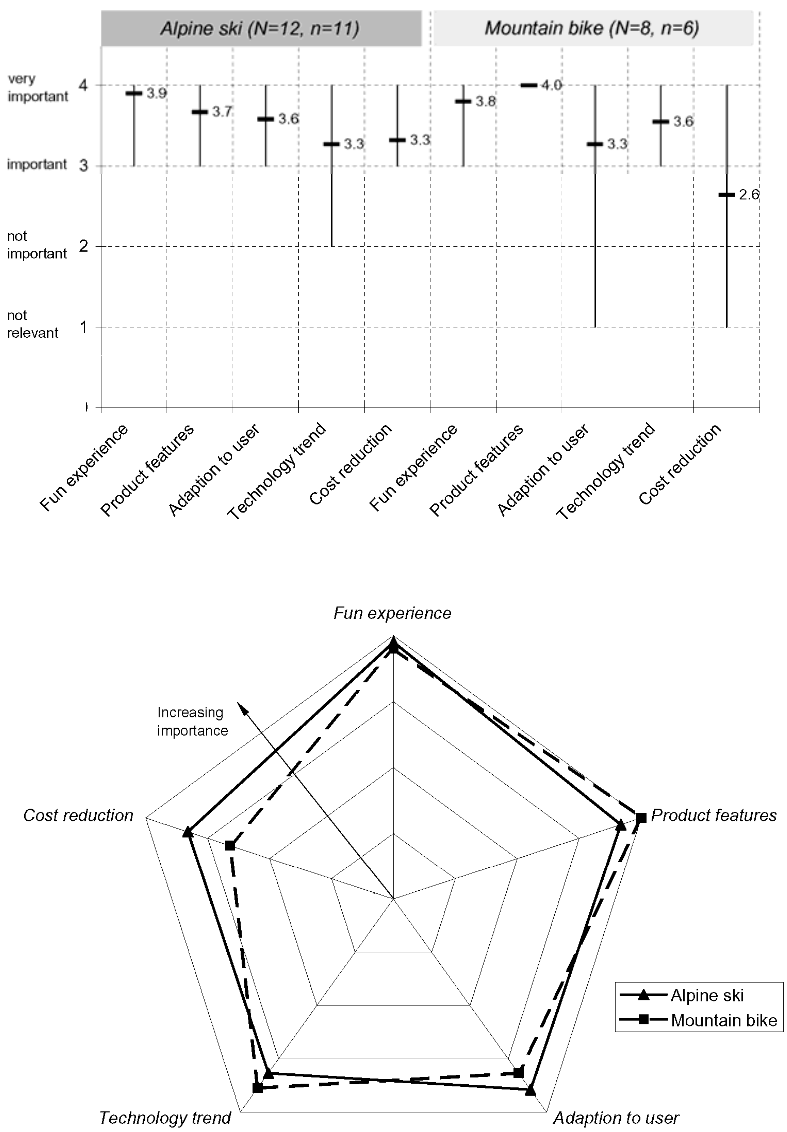



*Figure 3-2: Focus on product design by sports technology manufacturers.*

Focus on product design by sports technology manufacturers:

The participating companies were asked to provide statements about the influence of cost, product features, market adaptations, and technology trends on both new product design and design optimizations. These aspects provide a good impression about the relevance of product features in the environment of other influencing factors of a company. They also allow comparison to the findings about driving forces and obstacles for new designs presented in the preceding section.

As depicted in Figure 3-2, a stronger focus in the response categories can be observed for alpine ski manufacturers compared to those of the mountain bike manufacturers. The mean intra-item variances are 1.2 and 1.6 (with mean spans of 0.3 and 1.4), respectively. Both market bases identified the improvement of product features as the most relevant topic. For alpine ski manufacturers, adaptation of products to market influences as well as cost reduction and adaptation to technology trends follow up each other with respect to their importance. As for mountain bike manufacturers, technology trends appear to be more relevant and average “very important”, followed by market influences. Currently, cost reduction is clearly a less urgent topic for mountain bike manufacturers.

Importance of function, ergonomics, performance, optics and safety:

Generally, very high ratings were given to the importance of product features by both alpine ski and mountain bike manufacturers (Figure 3-3). The mean intra-item variances are 1.3 for the alpine ski sector and 0.4 for the mountain bike sector. Both function and performance were rated “very important” by alpine ski manufacturers, followed closely by the importance of optics. The average rating for safety given by alpine ski manufacturers was “important”, however, the ratings by the individual survey participants ranged widely from “not relevant” to “very important”. Alpine ski manufacturers gave ergonomics the lowest rating of the product features included in the survey, with ratings ranging from “not important” to “important”. Within the mountain bike manufacturers surveyed, performance was rated as the most important product feature with all participants reporting that performance was “very important” for product designs. Function and optics also received an average rating of “very important”; however, several individual manufacturers rated the features as “important”. The average ratings for safety and ergonomics were slightly less than those reported for function and optics.

Because of the importance of the outcomes, a plausibility test was conducted. The survey participants were asked to put the different product features in order of relative importance. The results of this additional survey showed that the participants consider performance to be the most important product feature, which is consistent with the findings when each of the sectors was analyzed separately. Similarly, the results showed that the participants all regard ergonomics as the least important product feature. The rankings for function, safety and optics are reordered to optics, function, and safety for the alpine ski sector and function, optics, safety for the mountain bike sector. The outcomes of the separate ratings presented above, however, do not differ considerably. Interestingly, safety is again ranked as the second least important feature for both alpine ski and mountain bike sectors.

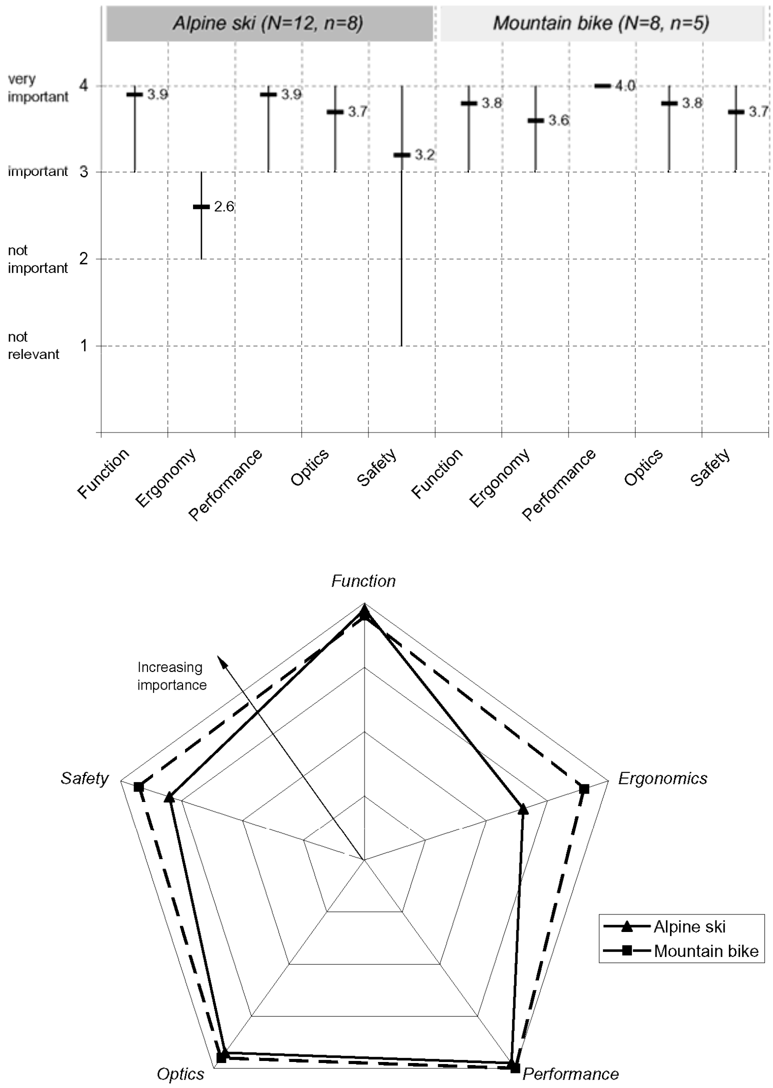



*Figure 3-3: Importance of product features from the sports technology manufacturers' point of view.*

How do sports technology manufacturers estimate the potential use of mechatronic components in or as part of sports technology?

Reasons for the minimal role of mechatronics in sports technology:

First, realization or the integration of mechatronic systems into sports technology is problematic. Several survey participants stated that realization has failed because of a general lack of know-how or because proper components were not available. Thus, the need for power supply and product reliability in harsh environments (e.g., cold, wet and subject to shocks) was addressed. Finally, large investments for development were named as a major problem and high product prices are not viable on the market.

Potential of mechatronic sports technology:

Despite the critical statements described above and the fact that sports technology manufacturers surveyed do not currently apply mechatronic in their products, a large percentage plan to apply mechatronics in future products (an average of 55.0 %). In addition, of those manufacturers surveyed, an average of 60 % believe that the potential for mechatronic application is high or very high. Some manufacturers believe mechatronics to be a powerful market trend. A summary of the survey results regarding the application of mechatronics systems is shown in Table 3-7. A review of the results shows that mountain bike manufacturers estimate the potential for the use of mechatronics in sports technology to be higher than do alpine ski manufacturers. In addition, the results show that they have more planned applications than alpine ski manufacturers.

*Table 3-7: Application of mechatronic systems in sports technology*

| *Alpine ski, N=12, n=6 (% of mentions)* | *Use of mechatronics* | *Mountain bike, N=8, n=5 (% of mentions)* |
|---|---|---|
| 0.0 | Current application | 0.0 |
| 50.0 | Planned application | 60.0 |
| 40.0 | High / very high potential | 80.0 |

Possible functions of mechatronic components in or as part of sports technology:

The statements given by the manufacturers generally refer to possible applications instead of to specific functions of products. Some of the possible applications described by the survey participants include the use of mechatronics for customer service, ski rental, as a product identifier in terms of RFID (radio frequency identification), in electrically driven bicycles, or gear shifts for bicycles.

Important specifications of mechatronic sports technology:

Special emphasis was placed on usability and durability issues. Proper power management for a long battery life, resistance against shocks, and other environmental impacts were named explicitly.

### 3.1.5 Discussion

Product novelties are mainly generated by spontaneous ideas, both in the alpine ski sector and in the mountain bike sector. Substantial new designs account for only one-third of all product novelties within the last three years, which makes it surprising that benchmarking is considered a dominant driving force for product novelties. This fact suggests that most companies compare their research and design results to their competitor's products, and that an open innovation process is uncommon. In addition, the low ratings for the importance of technology trends for product design support this apparent drawback in the product design process, which is most obvious in the alpine ski sector. Methodical approaches and the involvement of customers play a minor role in the design process. This agrees well with the outcomes regarding the systematic application of methods in the design process. Between 14.0 % (mountain bike) and 21.3 % (alpine ski) of basic engineering and sports science methods were applied to the design process.

User oriented aspects such as ergonomics and fun experience are typically disregarded or addressed by means of non-standardized surveys. This is especially surprising because fun experience was generally rated as a very important marketing aspect and as a main focus in product design. Ergonomics was identified as a main area of focus by alpine ski manufacturers, but was considered far less important by mountain bike manufactures. The manufacturers did not regard a lack of appropriate methods to be a limiting factor for product novelties. Perhaps this is because they either do not have methodical expertise or because the benefits of method application are underestimated. The two main obstacles in the realization of product novelties are limited human resources and high investments. In addition, a high degree of product diversification was also identified as a limiting factor for product novelties.

Performance parameters play a superior role in the importance of different product features in both sectors, followed closely by functional aspects. Despite the results discussed above, the importance of ergonomics was given quite a low rating by alpine ski manufacturers, and was rated much less important than all other aspects by both sectors. This may be because of a lack of systematic approaches in measuring and realizing aspects such as comfort and anthropometry. Optics is also considered to be very important in product features in both sectors, while safety is of greater importance for the mountain bike sector.

Alpine ski and mountain bike manufacturers do not currently offer mechatronic products. However, a high or very high potential for mechatronic sports technology implementation was estimated to be twice as likely by mountain bike manufacturers compared to alpine ski manufacturers. About 50 % of the companies surveyed plan to incorporate mechatronic applications in the near future, including customer services (alpine ski sector) and drivetrain components (mountain bike sector). None of the manufacturers surveyed are planning products to analyze motion or loads for training feedback, component stability monitoring. The realization is often hampered by high investment costs and a lack of engineering know-how to solve major problems such as power management and usability.

## 3.2 Sports retailer view

Sports retailers are the most important link between manufacturers and customers (athlete). Although internet-based distribution and direct selling are increasing, sports shops remain the backbone of sporting goods distribution (Vossen, 2005, pp. 87ff).

Because of their face-to-face sales activities and their position between the customer and the sporting good industry, retailers are an important source of information with respect to their view of sport and sports technology. The investigations conducted for this study again focus on alpine skis and mountain bikes. While the newspaper Münstersche Zeitung in the German town of bicycles reported that the “Bicycle sector is booming – 5.2 % gain in sales while total market shrinks” (Berg, 2009), the FOCUS only a couple of months prior had reported that “Skiing was yesterday – ski sector struggles to survive” (Nele Bode & Hinze, 2008). It is likely at least some of the decrease in ski sales was because of poor snow conditions, however, it is unlikely the entire downturn in the ski sector can be attributed to weather conditions. Product sales involve both psychology and knowledge of customers, in addition to knowledge about the products. Previously, only fragments of information could be found in the literature regarding the retailers' viewpoint on factors that determined the success of products. The study presented here for the first time introduced information regarding the importance of product features, sport motives, and innovation potentials in the context of sports technology design.

*Term description*

**Sports shop** and **sports retailer**

„A sports shop is a business focused on specialized trade of sporting goods. It is characterized by a sound sales advice provided by the sports retailers engaged in the shop.“

### 3.2.1 State of information

A brief overview of the German sports retail market structure is provided to help with understanding the market background. It also served as a basis for selecting the sample group used in this study. Around 11.000 businesses, including bicycle retailers, are engaged in selling sporting goods. The market share of the traditional types of sport shops is approximately 52 % with a slightly falling tendency (Vossen, 2005, p. 7). However, when including fashion and shoe stores, it has been stated that the market share increases to 60.1 % (ifo, 2003, P. 1). The remaining market share consists of discount retailers, mail orders (including web-based ordering) and large warehouse sport outlets. The entire sporting goods store sector was recently subjected to drastic changes when discount vendors and internet-based mail orders gained markets shares from 6.5 % in 2003 to approximately 9 % in 2006, mostly at the expense of traditional sport shops (Vossen, 2005, pp. 84ff).

Unlike traditional sport shops, discount vendors do not provide in-depth guidance on their product stocks. To accomplish this, the vendors do not typically employ knowledgeable staff and are therefore able to increase their profit margin by saving staff appropriations. In addition, most of the products sold at discount vendors are lower priced products that often lack higher quality standards but satisfy functionality expectations. Many examples can be found in the fashion sector, so-called functional sports wear (e.g. outdoor jackets). Recently, hardware products including hiking sticks, bicycle helmets, spotlights, and even mechatronic sports technology such as sports watches, heart-rate monitors and bicycle computers have entered the shelves of discount vendors. The increase in the products available at discount vendors suggests that there is a moderate amount of competition in the market of sports technology. Therefore, traditional sport shops would benefit greatly from the introduction of new technology-based products where their service expertise forms a unique selling point. Thus, the present study focuses mainly on the traditional sport shops as a source of information, supported by information from discount vendors.

### 3.2.2 Study design, materials and methods

Some basic information on the study design, measurement instrument, sample group, and execution of the study will be provided in this section.

In chapter 3.2.1, it was discussed that very little information is available regarding the possible involvement of retailers in the design of sports technology. This fact suggests an inductive approach. The study was therefore designed as an explorative, cross-sectional case study with single interviews as the data collection method. The survey was designed as a partly structured interview, meaning all questions were formulated explicitly but not necessarily posed as closed questions (Bortz, 2006, p. 238). The fact that the survey was designed to be receptive to additional information from the interviewee accounts for the explorative character of the study. For the closed questions where a rating scale was required, the following four-step scale categories were used: “very important” (4), “important” (3), “not important” (2), “not relevant” (1). The complete outline of the interview can be found in the Appendix 8.2.2. Prior to conducting the interviews, the participants agreed to audio recording, which was accomplished with a digital voice recorder.

Table 3-8 summarizes information on the structure of the German sports shop market by the size of shops. Based on the information in the table, the sports shops appear to be predominantly characterized by small- and middle-size businesses, which was also taken into account for the selection of the sample group. Although the presented case study is regarded as an appropriate approach to treat the research questions, some considerations about limitations in connection with the selection of the sample group should be discussed.

*Table 3-8: Structure of German sport shops by size (according to Vossen, 2005, p. 7)*

| *Turnover (Mio. EUR)* | *Market Share (%)* |
|---|---|
| < 0.5 | 37 |
| 0.5 - 2.5 | 52 |
| > 2.5 | 11 |

An attempt was made to locate businesses of different size to increase the variance as much as possible. Because of economic limitations, the interviews could only be conducted in the area of Munich. It should therefore be noted that regional distinctions influence the representativeness of the results. Munich, in contrast to other German cities, is characterized by a stable economical and socio cultural situation and the population is considered to be very involved in sports The retail shops and chain stores chosen for an interview were selected based on personal relationships established through other research projects and then randomly selected based on the size of the shop. All of the stores chosen for an interview agreed to participate in the collaboration and the interviewees held comparable positions within the businesses (see Table 3-9).

*Table 3-9: Basic information on the interviewed retailers*

| | *Date of interview* | *Position of interviewee* | *Staff* | *Type of store* | *Alpine ski retailer* | *Mountain bike retailer* |
|---|---|---|---|---|---|---|
| *Retailer 1* | 2008/07/02 | CEO | 1300 (overall) | 14 stores | X | X |
| *Retailer 2* | 2009/02/13 | Head of sales | 20 (store) | 14 discount stores | X | |
| *Retailer 3* | 2009/04/28 | Owner | 7 (store) | Single store | X | |
| *Retailer 4* | 2009/02/13 | Owner | 4 (store) | Single store | | X |
| *Retailer 5* | 2009/02/13 | Owner | 2 (store) | Single store | | X |

### 3.2.3 Execution and data analysis

The interviews were conducted by the author of this thesis, exclusively on-site at the sports shops without further audience, with the exception of retailer one in which the interview was conducted at the central office. The interviewees were first presented with standardized information on the background of the study, given an assurance for the anonymity of the results and the exclusive use for scientific purposes. The participants were then shown different question blocks and asked to provide some items about general business numbers (staff, etc.). Some questions that referred to concepts beyond the scope of this thesis were disregarded. The data analysis included replaying the audio data while making written notes of all statements.

### 3.2.4 Results

The survey of the sports retailers was conducted for the alpine ski sector and the mountain bike sector separately. Nevertheless, most of the results are presented in a cumulative manner for clarity or because the statements were of a general nature. The statements represent the interviewees' point of view.

What are the apparent motives of people for exercising sport?

The results of the interviews indicate that some sports motives, such as fun experience, are consistently present in the majority of groups of people exercising sport. Other motives appear to differ mostly with the age of the customers. When it comes to exercising, there is a clear difference between younger and older customers' demands. Younger people tend to focus on sports that are more adventurous, involve greater risk and have a greater thrill, while people 55 years or older tend to exercise for health and wellbeing. Table 3-10 depicts the responses from the survey participants and provides an overview of the corresponding number of mentions for each item.

*Table 3-10: Sport motives and weighed motive groups according to mentions*

| *Mentions* | *Sport motive groups (% of mentions)* |
|---|---|
| Enjoyment<br>Fun and freedom<br>Positive motion experience<br>Fun | Fun experience<br>80.0 |
| Reduce risk of afflictions<br>Improve cardiovascular system<br>Health<br>Health | Health<br>80.0 |
| Compensation and balance<br>Compensation to work<br>Wellbeing | Wellbeing<br>60.0 |
| Regain fitness<br>Fitness<br>Success experience | Achievement<br>60.0 |
| Thrill<br>Risk and adventure | Thrill<br>40.0 |
| Social connection | Socializing<br>20.0 |

Which are the main target groups, what are their characteristics and which groups are focused in the future?

All interviewees, explicitly or implicitly, implied that traditional market segmentation is difficult to achieve within the sports market. Generally, with the exception of the fashion market, the sports market cannot be divided into separate target groups. Indeed, the sports market is diverse and complex in its constitution, particularly when considering the countless number of sporting activities and the indistinct transition between sports and leisure activities. A more meaningful approach to identifying target groups is to concentrate on people's motives rather than on specific groups. Figure 3-4 shows a model to analyze these different influences.

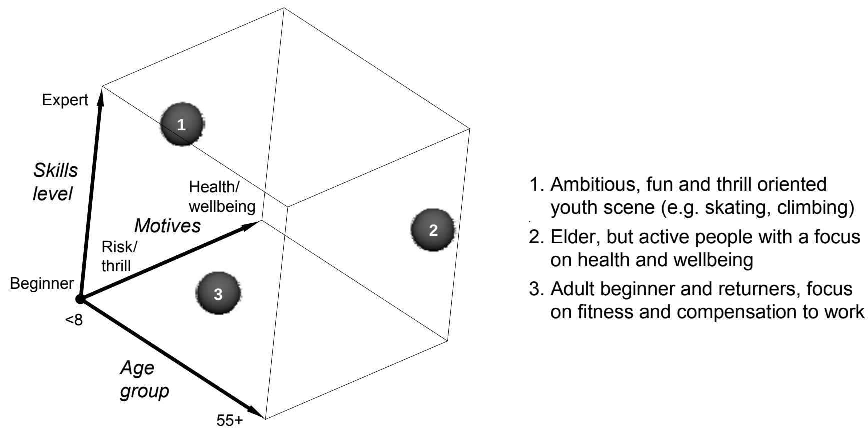



*Figure 3-4: Scheme to visualize the retailers' future target group specification.*

In contrast, differentiation of focus products is more easily made. Generally, small mountain bike shops offer more specialized products. While large chain stores appeal to athletes of all skill levels and age groups, the small shops concentrate on more specific clients. Examples of this specific clientele might include, youths interested in freeride bikes or the moderate cyclist who is interested in a cruiser-type bicycle. In the ski sector, the survey participants indicated that they try to appeal to the entire range of customers. On average, their largest group of customers is comprised of fun-oriented skiers, while achievement-oriented skiers do not regularly frequent ski shops.

The retails indicated that in the future, more effort should be made to match the product portfolio to specific sports motives. For the chain stores, the alleged ambitious leisure sports athlete is the most important customer group. This group of people is typically driven by a combination of motives including achievement, fun experience and freedom. From the retailer's point of view, this target group is important because it represents the so-called "multi-sportsman" who is into various cost intensive outdoor sports such as cycling, hiking, skiing, or water sports. More ambitious customers who concentrate on a specific sport tend to purchase their equipment from smaller expert stores. In addition, the smaller stores will be able to cater to people requiring individualized products. They will continue to specializing in and develop specific segments because higher margins can be achieved in these areas. No considerable tendency toward specialization or focus was reported for the ski sector. The "under 25 years" group and the so-called "best agers" (50 years and upwards) were identified several times as focus groups while the age group in between was not expressed explicitly as a target.

What are the driving forces and obstacles for product novelties in the area of sports technology?

Product novelties launched between 2006 and 2008 in the area of alpine skis and mountain bikes were identified as optimizations or modest variations of existing products by all interviewees. The time frame 2006 to 2008 was chosen because product designs that were completed by sports technology manufacturers in 2006 should have been launched within this period. This suggests consistency between this study and the study of sports technology manufacturers presented above.

In the ski sector, large demand and the need for market share hinder sustainable innovations. The retailers interviewed indicated that they would expect innovations to occur in the area of ski boots and ski bindings. Many of the redesigned ski models differ only slightly in shape or color, and much less significant in functionality. A general increase in the amount of summer outdoor sports has greatly benefited the mountain bike sector. However, most of the traditional areas of optimization, including frame geometry and weight saving constructions, have been exploited in products intended for the volume market — products that are of great importance to the retailers. Mechatronics in sport for motion and performance analysis was listed by two retailers as a possible source for real innovations. Recent product optimizations, however, have led to a considerable amount of increased demand and product turnover rates. Some important product novelties are given in Table 3-11.

*Table 3-11: Type of product novelty in the period 2006 to 2008 from the retailers' point of view*

| *Type of product novelty* | *Retailers' view (% of mentions)* | *Examples* |
|---|---|---|
| New product, real innovation | 0.0 | Carving ski, full suspension for MTB's (mid to late '90is)<br>Disc brakes for MTB's (~'00) |
| Novelties based on optimization | 100.0 | Twin tip skis (freeride)<br>Lock out for MTB forks<br>Single speed bicycles<br>Dirt bikes, BMX, freeride bikes |

The retailers' overall impression of the driving forces for product novelties was that ideas for innovative products are frequently generated by a relatively small group of people, individual inventors, called enthusiasts, or former professionals. New products are often developed in small start-up companies through a trial-and-error approach, while product optimizations are more frequently made in the research and design departments of large manufacturers. Another source of innnovation is youth scenes were new ideas come about in a game-like environment. The industry eventually absorbs promising new sports trends. A summary of mentions is given in Table 3-12. Rarely, suggestions for product optimization are provided by retailers themselves.

*Table 3-12: Driving forces and limiting factors concerning product novelties from the sports retailers' point of view*

| Driving forces | | Limiting factors | |
|---|---|---|---|
| + + + | Try&error by freak and former professionals | - - - | High prices for introduction |
| + + + | Trend scouting by industry | - - - | Weak cost performance ratio |
| + + | Systematic design in industry | - - - | Concentration on show effects |
| + + | Youth scenes | - - | Lack of innovation mentality |
| + | Retailer input | - - | Low R&D rates in industry |
| | | - - | Lack of durability |
| | | - - | Lack of functionality |
| | | - | Bad weather conditions |
| | | - | Undervalued distribution |
| | | - | High investments for retailers |

An example of a local (German) invention, and a contribution to the mountain biking sector, is the Bergmönch. It is a full suspension downhill scooter designed by two engineering students for use on gravely trails. The inspiration behind the design was for a convenient alternative way to quickly get downhill, but that was also a lightweight, portable device. A leading bicycle manufacturer partnered with the designers and contributed production expertise and marketing power (Figure 3-5).

*Figure 3-5: The Bergmönch, an example for youth scene product novelty.*

Generally, the most prominent obstacle in the realization of product novelties are the high sales prices during the market launch phase. This fact was noted by all of the survey participants and has several dimensions. First, the bill of materials is usually higher for low production numbers. Second, the cost-performance ratio for products that have recently undergone optimization, such as a redesign or repainting, is often weak, leading to low sales numbers. This is a general problem for the sports equipment (hardware) market where ambitious customers encounter stagnating or even decreasing quality, particularly in the bicycle sector. Proper product pricing is a serious issue in the sports technology market, particular in the ski market where prices have increased nearly 100 % within the last 8 years. Also, the conventional combination of ski and binding types and a general innovation "vacuum" hinders the development in the ski market.

One reason for the lack of real innovations in sports technology is the size of the equipment manufacturers. They are mainly small- and middle-size businesses with low rates of investment in research and design. Especially in times of economic stagnation or downturn, when a clear innovative strategy is advisable, visionary product strategies and ongoing investments are rare. In addition, there is no institutionalized information exchange in which manufacturers utilize the retailers' market experience as input for improvements.

What is characteristic about sports technology?

The interviewees identified three aspects that are characteristic of sports technology. First, sport is almost always connected to very personal motives. Therefore, a kind of emotional attachment is often formed between users and a piece of sports technology. Athletes often consider personal sports technology as body extension. Such equipment is serviced and cleaned frequently, and less often is considered disposable. There is more necessity for quality and functionality. Some devices are frequently subjected to revision and tuning. Second, the selling process of sports technology usually requires a substantial amount of illustrative, individual support for the customer. Third, sports technology has to be easy to use and highly self-explanatory.

How do retailers value the importance of specific product features?

A variety of topics were analyzed from the interviews to answer this research question. A summary of the topics covered follows below. The values for the visualization in the figures were calculated in a similar way as presented in chapter 3.1.4.

How is the importance of the product features, including function, fun experience, ergonomics, performance, optics and safety, estimated by sports retailers?

Figure 3-6 (top) shows the mean values and variances of all product features analyzed for both alpine ski and mountain bike retailers. The mean intra-item variances (the mean standard deviation was not calculated because of the small sample group size) are 1.2 and 0.6 for alpine ski and mountain bike, respectively. The mean values over all product features account for 2.5 and 3.5 (with spans of 2.4 and 1.0) for alpine ski and mountain bike, respectively. The product's function and safety were rated lower by alpine ski retailers in comparison to mountain bikes retailers. Interestingly, safety rated exactly opposite by the different sectors. While safety is a core topic for mountain bike retailers (rated as “very important”), it ranks surprisingly low (“not relevant”) for alpine ski retailers. Performance is considered the most important feature for alpine ski retailers and ergonomics plays a key role alongside safety aspects with respect to mountain bikes. The ratings for function and optics all averaged on an equal level (“important”) for mountain bikes, while performance is considered slightly more important. For alpine skis, ergonomics was rated as slightly more important than optics (“important”).

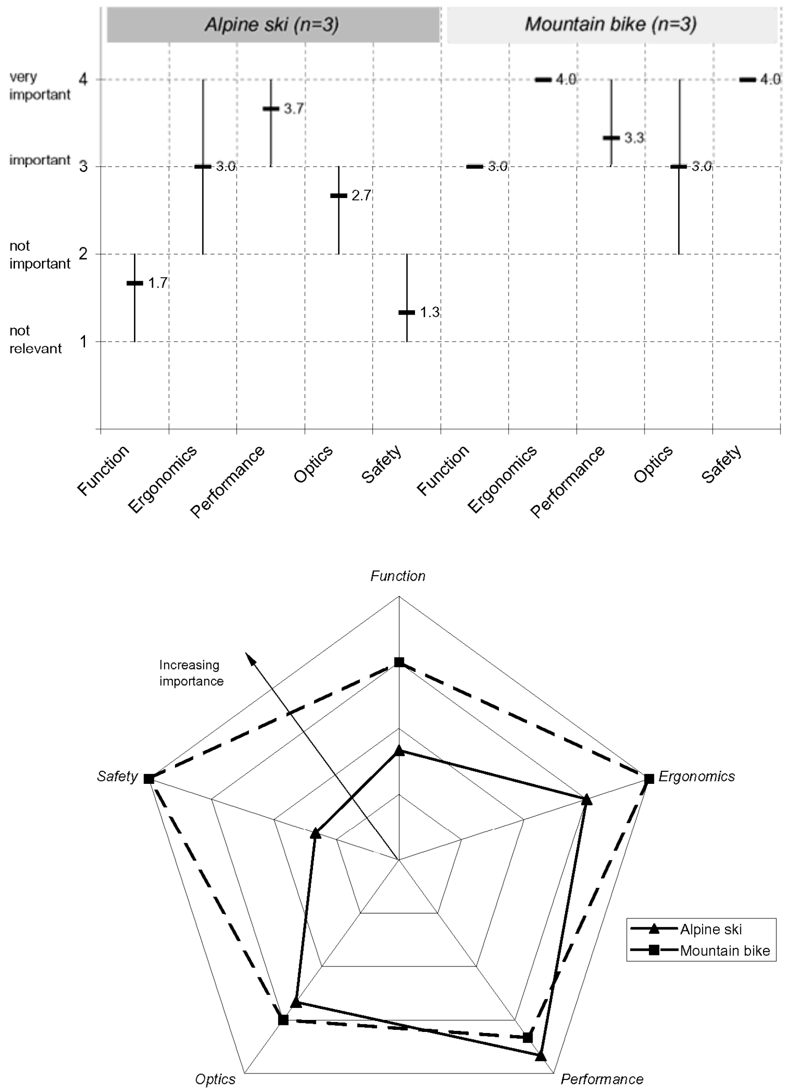



*Figure 3-6: Importance of product features from the retailers’ point of view (mean values).*

Critical product features and product deficiencies:

All interviewees who responded to this question (four out of five) named safety as the most underestimated topic in sports. In this context, the expression “safety” has three dimensions. First, personal safety equipment (e.g. helmets or protectors) remains undervalued in the sense that people concentrate on optical features rather than on quality and function.

In Germany, the sales figures for ski helmets rapidly increased after several ski accidents received extensive media attention. Other safety products that have been selling well include protectors for the back, hands and knees. However, safety standards and needing the perfect fit play a subordinate role in the area of safety and a general awareness of the importance of personal safety equipment has not yet been developed to a satisfying degree. This was acknowledged both for the alpine ski and the mountain bike sector.

The second dimension of safety is that the safety aspects of sports technology itself are seldom visible to the user. Almost all products are certified by certain standards such that a differentiation between quality and safety is very difficult. Inexpensive products of minimal quality are too often preferred by customers. In regards to alpine skis, the problem products are often the all-in-one solutions which include a combination of skis and bindings. The binding offers the most safety and is the most quality relevant part of the package, and as such should be subject to individual configuration. New materials for mountain bike frames, such as carbon fiber, are heavily promoted by the industry and sold at higher prices, while relevant disadvantages and safety risks because of damage are often concealed.

*Figure 3-7: Freerider doing tricks.*

The final dimension of safety involves the evolution of existing sports technology. This evolution includes the development of carving skis or sports technology developed to specifically imply that trend sports are easy to learn and the technology provides a safe experience in return for thrills and fun. Often, these experiences are connected to higher speed and risky behavior. Freeriding, for example, is a popular sport with a subculture component that is often alluring to young people. However, the possibility of injury from attempting tricks is underestimated when the appropriate protection is not used (Figure 3-7).

Beyond the safety aspect, a decrease of quality is observed in some components. Current bicycle parts, gear shifts for example, are less durable and mechanical tolerances are wider than those associated with previous models. In the ski sector, ergonomic features may be neglected. Ski boots often lack correct fit and produce stress and discomfort for the user.

How do retailers estimate the potential of mechatronic components in or as part of sports technology?

Reasons for the minimal role of mechatronics in sports technology:

The potential for mechatronics in the context of sport and sports equipment was generally regarded conservatively, and in some cases was considered controversial. The list of reasons given by the retailers for the limited application of mechatronics in sports technology was headed by the impression that products that include the use of mechatronics appear to lack clear customer benefit. Three out of five interviewees shared this opinion. The responses not only refer to useless product functions, but also allude to the fact that the industry has failed to give simple explanations and reasoning for their mechatronic products. This is directly linked to the problem of products that are too complex. Complex products are typically purchased and used by a relatively small number of experts and technology aficionados. High sales prices are often a result of the heavy investments made into the research and design of the products, as well as from small production numbers at the time of the product launch. On the manufacturing side, the main problems appear to be a lack of know-how and experience to bring together sport and technology.

Potentials of mechatronic sports technology:

The estimated potential for mechatronic sports technology is variable (Table 3-13). All of the retailer interviewees noted a certain potential, subject to certain conditions. The (smaller) mountain bike retailers shared the opinion that functionality from mechatronic systems in cycling would be limited exclusively to a small number of ambitious users. On the other hand, the two (larger) alpine ski retailers share the opinion that mechatronics do have great potential for mass markets as soon as plausible benefits can be produced for reasonable prices. Retailer one expressed that an expedient application of mechatronic systems in sports could dominate the sports market. However, the challenge is to bring together mechatronic systems and specific sports functionality, and integrate these systems in the self-conception of daily life.

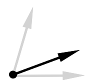
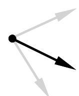
Possible functions of mechatronic sports technology:

The use of mechatronics in sports technology could be beneficial when applied to the development of supplemental product functions involved with the topic of safety. Avalanche warning systems, automatic ski bindings and active damping systems were proposed as examples that could benefit from the use of mechatronic sports technology. Furthermore, advice and support were indicated as other potential fields for the introduction of new products. Examples of products that could be introduced could include foot pressure measurement analysis for skiing, heart rate monitors, digital advisors and training partners, altimeters, or portable navigation systems.

Important specifications of mechatronic sports technology:

As shown in Table 3-13, product simplicity and usability were named as prerequisites of mechatronics sports technology by all of the interviewees.

*Table 3-13: Retailers' point of view about potentials and limitations of mechatronics in sport*

| *Topic* | *Tendency/ Important facts* |
|---|---|
| Reasons for underpart | Customers don't see benefit<br>High product price<br>Too complex<br>R&D expenses<br>Lack of know how<br>Customers don't know |
| Potential |  |
| Possible functions | Safety & advice<br>Exercise support<br>Vital parameters<br>Motion analysis<br>Adaption of equipment |
| Important specifications | Good usability<br>Simplicity<br>Self explanatory<br>No hassle with power supply |
| Recommended pricing |  |

Recommended pricing for mechatronic sports technology:

There is a consensus among the survey participants that it is almost impossible to reach larger customer groups with a high price strategy. There is also a consensus that a successful market introduction would simply include low- to medium-priced products that have a clear customer benefit. There is a market for higher price products, but it is very limited in terms of achievable sales volume. The lower price segment for mechatronic sports technology starts at around 20 € (e.g. simple bicycle computers such as the Ciclosport CM4.1 for around 18 €) and ranges up to a maximum of approximately 100 €. The most expensive products are currently around 600 € for multifunctional devices (heart rate, altitude, speed, etc.). A good example of a high price strategy is the electronic control unit and binding Neox EBM 412, introduced by the Austrian ski manufacturer Atomic in 2003, which was initially sold for over 1000 €. Figure 3-8 depicts both a very low price and an extreme high price product.

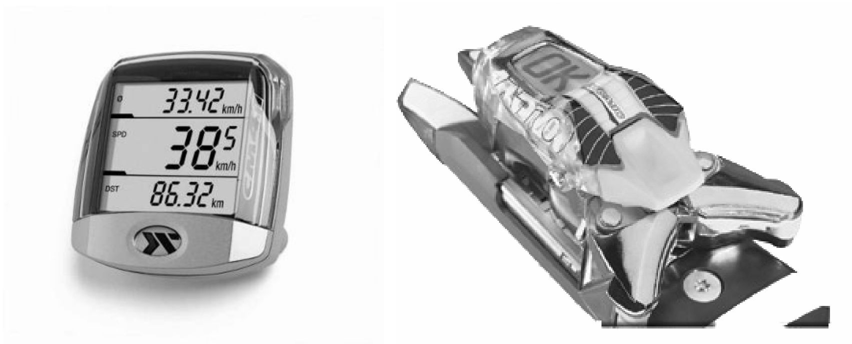



*Figure 3-8: Low- and high-priced products. Bicycle computer Ciclosport CM4.1, about 14 € (left), ski-binding Atomic NEOX EBM412, about 1.000 € (right).*

### 3.2.5 Discussion

The sports retailers emphasized that they generally concentrate on user groups driven by specific motives and separated by their level of skill, rather than on age-based demographic groups. Fun experience and health were named as the two most important sport motives, followed by the pursuit of health and reaching specific achievements. In the field of bicycles, uses range from sightseeing and leisure activities to amateur sports which can be as demanding as professional sports. For each of these groups, enjoyment has a different meaning. In skiing, very few people focus on the achievement of certain goals. In terms of selling products, this means that sports technology will have to cater to the specific “sports worlds” in which they are being used.

The results of the interviews suggested that most of the product novelties developed during the past three years have been based on optimizations. Very few sports technology manufacturers prioritize systematic innovation, and most of the innovations were made by independent inventors which eventually found their way to industrialization by the sport companies’ trend scouting. While some important optimizations were made in the mountain bike sector (for example, suspensions and disc brakes), the ski sector was almost entirely driven by appearance and marginal improvements (for example, twin tip skis for freeriding). The product diversification greatly increased without addressing specific user groups. Another problem with product novelties, especially in the skiing sector, is that the constantly increasing product price level is not absorbed by the market. In addition, the durability and functionality of products remains mostly consistent or even decreases in terms of cost-performance ratio.

In this respect, customer demands were characterized as ambivalent. While a large portion of leisure sports athletes claim to want higher standards of functionality, especially in the mountain bike sector, others respond more to lower prices and aesthetic aspects. In any case, the resulting product diversity is confusing to customers. A slight increase in the awareness of adequate cost-performance ratios in terms of solid functionality and durability can be observed over the last three years. This is also supported by the retailer ratings for the importance of aesthetics which were reported to be on a medium to low level in both sectors with a lower rating given by the mountain bike sector than the skiing sector While ergonomics and performance aspects play a major role both in skiing and cycling, product safety is much more important in the mountain bike sector because of several recent reports about broken forks, handlebars and frames in the media. In skiing, functional aspects were only regarded as relevant in connection with the ski binding. For mountain bikes, the entire system must be subjected to higher efforts in product safety. In fact, retailers see much more potential in the realization of safety relevant product features, such as safety ski bindings (to prevent ruptures of ligaments), as well as in individualization with respect to the fit of products, for example ski boots or specifically designed frame geometries for women (ergonomics). In contrast, personal safety equipment is becoming increasingly valuable to customers. A major obstacle for all safety aspects is the lack of transparent testing and certification that would allow the comparison of products on an objective basis. To date, both low and high quality products are generally certified by equal standards. However, sports technology manufacturers do not currently consider product safety a selling proposition.

The potential role of mechatronic systems in or as part of sports technology in leisure sports as reported by sports retailers was variable. The most important barriers that mechatronic products need to overcome are elevated prices and overly complex user interfaces. Mechatronic sports technology must convey a clear message regarding its potential benefit for sports activity, along with ease of usability and long battery lifetime. The two larger retailers interviewed regard mechatronics as a necessary source for product innovations in sport. Provisions of safety and advice features, as well as the analysis of motion and vital parameters were named as possible fields in the enhancement of functionality. The three smaller retailers indicated that mechatronic systems can only serve niche markets and specialists. In terms of pricing, it was stated that a limit of 100 € should not be exceeded if volume markets are targeted.

## 3.3 Athlete view

### 3.3.1 State of information

The outcomes of most design projects in the area of sports technology are based on an attempt to evaluate user needs. Some examples can be found in student projects designing a new bicycle frame (Valtingoier, 2004), a fun boat for leisure sports (Blümel, 2004), or a carving bicycle (Hoisl, 2005). This approach focuses on technical characteristics in terms of product features. In addition, it can be helpful to obtain knowledge about the athletes' motivational background for exercising sport to match and adjust product features accordingly (which mainly refers to product functionality). The present study was conducted to evaluate product suitability.

### 3.3.2 Study design, materials and methods

Similar to the two preceding studies, this investigation was designed as an exploratory cross-sectional survey. The survey was conducted on two different dates with two different groups of participants to homogenize the sample group in terms of the mean age. The master's thesis by Hinz contributed to the results (Hinz, 2009).

The survey was conducted using a standardized questionnaire. The majority of questions were consistent with the preceding surveys. A question about important aspects regarding purchase decisions was included to account for the customer perspective of the attractiveness of sports technology. Again, a four level rating scale was implemented. The full outline of the online questionnaire can be found in Appendix 8.2.3. Data collection was performed by means of an online questionnaire. For the second part of the survey, the questionnaire was modified slightly (some items were excluded as they were deemed irrelevant).

Because the survey was designed to address the skiing sector, the sample group was recruited from a group of active skiers. The link to the online questionnaire for the first survey was published in the German Ski Instructor Association (DSLV) newsletter which is distributed to approximately 10.000 addresses. The second survey was addressed to approximately 500 members from a major regional ski school's e-mail distribution list.

To obtain information on the sample group's level of sports activity, the participants were asked to indicate their number of ski days per year (Table 3-14). In addition, all participants stated that they exercise sports regularly (at least one time a week). The sample group was thus characterized as having a medium to high activity level.Basic information on the sample group is given in Table 3-15.

*Table 3-14: Ski days per year, statements of the sample group*

| *Ski days per year* | *N=404, n=268 (% of mentions)* |
|---|---|
| ≤ 10 | 45.9 |
| 11-20 | 20.8 |
| 21-30 | 14.3 |
| 31-50 | 12.3 |
| >50 | 6.7 |

*Table 3-15: Basic information on the athlete survey and the corresponding sample group*

| *Sample group parameter* | *Specification* |
|---|---|
| Size | N = 479 |
| Respondents | n = 317 |
| Return rate | 66.2 % (of N) |
| Gender | f = 37.8 %, m = 62.2 % |
| Age, mean | 30.0 y (SD = 10.3) |

### 3.3.3 Execution and data analysis

Before the questionnaire was posted online, a preliminary test of five independent editors was conducted to assess comprehensibility and to fix faults in the online software. For execution of the questionnaire, an internet link was distributed via e-mail to all potential participants of the sample group as described above. The first survey was available online from June 29th, 2008 to August 13th, 2008. The second survey was available online from December 16th, 2008 to March 10th, 2009. For data analysis, the two response sets were combined. Because of the different sample sizes, weighting factors were used for statistical analysis.

### 3.3.4 Results

Which are motives of people for exercising sport?

Three sport motives were rated almost twice as often (80 %) as the rest of the motives. The top three sport motives, in decreasing order of response, were fun experience, achievement of sports goals and wellbeing (Table 3-16). Thrill is the fourth most important motive, followed by socializing and health. Both socializing and health received an almost equal number of approximately 40 % of the mentions.

*Table 3-16: Sport motives of the sample group*

| *Sport motives* | *N=404, n=278 (% of mentions)* |
| --- | --- |
| Fun experience | 87.6 |
| Health | 40.3 |
| Wellbeing | 80.3 |
| Achievement | 85.2 |
| Thrill | 52.4 |
| Socializing | 40.4 |

What is characteristic about sports technology?

The participants were asked to indicate the three most important characteristics of sports technology. An average, 11.5 % of the participants did not respond to this question. The answers that were received were classified into six categories (Table 3-17). Two-thirds of all answers refer to a specific functionality as the most important characteristic of sports technology. The second most important characteristic identified encompassed a variety of emotional aspects, followed by optics/image and quality. Pricing was not identified as a topic of interest here.

*Table 3-17: Categories of characteristics of sports technology named by the athletes*

| *Categories of characteristics* | *N=330, n=292 (% of mentions)* |
| --- | --- |
| Functionality | 61.2 |
| Emotions | 11.8 |
| Optics/Image | 6.7 |
| Quality | 6.1 |
| Price | 2.7 |
| Not specified | 11.5 |

Many responses referred to aspects that are subject to particular differentiation in the context of sport. Examples of frequently named aspects include lightweight design, optics, robustness and quality. Some of the most striking statements with respect to their uniqueness for sports technology were filtered from the list. Thus, characteristics of sports technology lay in the following:

- purpose to facilitate physical exhaustion and comparison of physical performance,
- fact that they are motivating with respect to physical activity,
- purpose to support the improvement of motor skills in terms of varying motions,
- possibility of individualization for different types of bodies,
- support and improvement of health,
- dynamics of its use in unity with the human body.

How do athletes value the importance of specific product features?

The question was posed with respect to two aspects: namely the importance of general aspects which are relevant for the purchase of sports technology and the evaluation of the importance of specific product features.

Which product related aspects do athletes focus on for purchase decisions?

In general, all aspects were rated relatively high by the survey participants. The mean value for all aspects was calculated to be 3.1, which corresponds to a rating of "important". The mean standard deviation over all items was 0.67 while the span between the mean values of the items was 1.05. Consequently, inter-aspect ratios were given special consideration. The most prominent aspect in the athletes' rating was quality/durability (rated as "very important" on an average), followed by functionality and the cost to performance ratio (Figure 3-9). Interestingly, the importance of "extroverted" issues such as image and brand were rated lower by comparison to the other aspects, with optics reporting only a slightly higher level of importance. The importance of cutting-edge technology and materials fall between the ratings reported for optics and functionality.

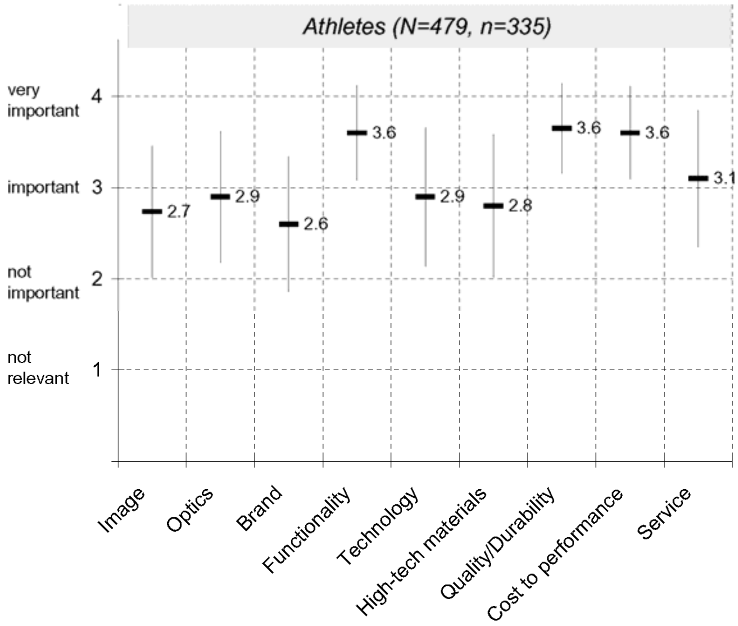



*Figure 3-9: Focus for purchase decision, athletes' point of view.*

How is the importance of the product features, such as function, ergonomics, performance, optics and safety, estimated by athletes?

Again, the mean ratings are relatively high for all items (3.42), and hence relative ratios were used for presentation. The mean standard deviation is 0.59 with a span of 0.9 between the mean ratings of the items. Function is considered the most important product feature with a gap of 0.4 scale units to the next important feature, performance. The importance ratings for safety and for ergonomics were approximately equal, while optics was rated as least important (Figure 3-10). Apart from the ratings in the closed questions, the participants were given the opportunity to provide additional information on what they thought should be important product features. Other important features identified include comfort (features on a product which increase the comfort while using it), compatibility (ability to interact with older equipment or other sports technology), quality (refers to the durability of the components)[6] and usability (complexity of a product with respect to its usage).

[6] This aspect was excluded from the survey due to the universal meaning.

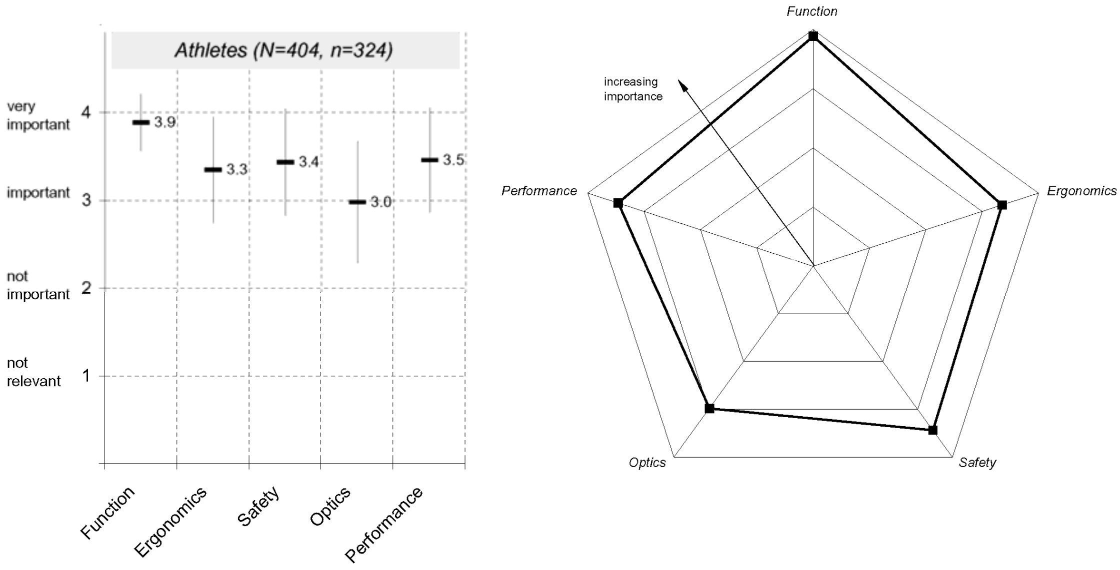



*Figure 3-10: Importance of product features from the athletes' point of view (mean values).*

How do athletes estimate the potentials of mechatronic components in or as part of sports technology?

Current use and potentials of mechatronic sports technology:

To evaluate the market penetration of particular mechatronic systems in sport, the participants were asked to identify which equipment they already use (Table 3-18). Apart from the very frequently used heart rate monitors (used by nearly two-thirds of athletes), GPS navigation use was reported by around one-sixth of the respondents. In addition, the use of heating soles for skiing appears to be increasing. The use of other mechatronic systems is marginal. MP3 players are not considered in this context. Approximately 90 % of the participants stated that they estimate the potential of mechatronic systems in future products to be high or very high. This is, however, subject to a variety of preconditions.

*Table 3-18: Overview of current use, potentials and specifications of mechatronic sports technology from the athletes' point of view*

| *Topic* | *N=404, n=288 (% of mentions)* |
|---|---|
| Use of mechatronics | |
| Heart rate sensor | 58.3 |
| Integrated MP3 | 19.1 |
| GPS navigation | 16.7 |
| Heating sole | 8.0 |
| Avalanche rescue | 1.7 |
| Watch | 1.4 |
| Bicycle computer | 1.0 |
| Step sensor | 0.3 |
| Potential | |
| High / very high | 87.0 |
| Possible functions | Measurment of velocity<br>Reliable calorie wastage |
| Important specifications | Wearability (no restrictions in mobility)<br>Usability (easy to use)<br>Weather proof<br>Low weigth<br>Long battery lifetime<br>Handiness (small form factor)<br>Durability / reliability<br>Shock resistance<br>No dangerous materials |
| Recommended pricing (motion feedback system) | 123.81 EUR (mean value)<br>95.06 EUR (standard deviaton) |

Possible functions and important specifications of mechatronic sports technology:

Interestingly, only two possible functions were suggested for mechatronics in sports technology despite the fact that a large percentage of people believe these systems have potential. The answers regarding important specifications were more constructive. They are listed in descending order of mentions in Table 3-18. Generally, functional aspects such as wearability and usability dominated the ranking, while optics, for example, were not included among important aspects.

Recommended pricing for mechatronic sports technology:

The mean recommended price was in the range that was also suggested by the retailers, although the large standard deviation has to be taken into account. The 100 € to 150 € range is generally regarded as a reasonable pricing for such products.

### 3.3.5 Discussion

The athletes' motivational background regarding their sports activities is characterized by a strong emphasis on a fun experience, wellbeing and achievement of sports goals. However, motives such as thrill, health and socializing were also named as vital driving forces for sports activity. Based on the results, it appears that athletes do not regard sports technology as directly contributing to their emotional experiences. Approximately 12 % stated that emotional attachment is an important characteristic of sports technology while more than 60 % of the participants believe that functionality to be most important characteristic. Functionality was also considered to be very important with respect to making purchase decisions. In summary, basic product function is by far the most important product feature. In contrast, safety, ergonomics and performance parameters were rated as important, but with considerably lower importance.

Surprisingly, optics and image were rated as relevant characteristics by only approximately 6 % of athletes. Inconsistent statements were provided regarding the meaning of product quality. While quality was not regarded as an important characteristic of sports technology, it was rated as crucial with respect to purchase decisions, along with a sound cost to performance ratio. It is remarkable that the athletes' interest focused on aspects which directly affect the use of sports technology. Underlying technologies or high-tech materials were rated lower. Sports technology is regarded as a means to improve dynamic motor skills in unity with the human body. In this context, the ability to adjust sports technology to individual body measures or other individual parameters is regarded as a core prerequisite.

Heart rate monitors were the only largely reported mechatronic sports technology used by the athletes surveyed. However, approximately 17 % of the athletes indicated that they already use GPS navigation in sport. The very low incidence of bicycle computer and watch usage are questionable, particularly considering sources that state higher percentages (Hintemann, 2007). In contradiction to the relatively low reported use of mechatronic sports technology, the athletes stated that it does have a very high potential future use in certain cases. Specific instances where the technology could be employed include the measurement of skiing velocity or reliable calorie monitors. Motion analysis or other more sophisticated applications were not named explicitly. The athletes also indicated that as preconditions, the products should be robust, very easy to use, and not inhibiting during sports activity (with respect to weight, form factor and attachment). In addition, they also stated that pricing should be area of 120 €.

## 3.4 Summary of key aspects in sports technology design

The nature of sport is strongly related to change processes in the social environments in which sport takes place. The contemporary definition of sport that was proposed at the beginning of this thesis accounts for these change processes. It describes sport as an activity that aims to achieve artificial motion tasks primarily for reasons of enjoyment or self-realization. On this basis, different viewpoints were analyzed with respect to characteristics of sport motivation and sports technology for alpine skiing and mountain biking. Because product functionality is implicitly evaluated by the athletes' perception, these findings should further fit into a concept of systematic design of sports technology.

### 3.4.1 Key findings

The results of the surveys are summarized in Table 3-19. A general trend can be observed towards individualization and outdoor sports, which is also supported by several recent market surveys (Vossen, 2005; Weck, 2009). Individual sports are gaining popularity in the realm of sports activity. The freedom to move, opportunity for spontaneous motion, and fast pace in combination with rotatory motion seem to drive the growth of these activities. Youth cultural sports, such as freeriding, account for the trend towards the extreme. However, elder athletes are becoming more active and have begun to join leisure sports that were formerly limited to younger generations (for example, inline skating and mountain biking). An important sport motive for all age groups is fun experience. Enjoyment of motion is foremost in the fun experience, followed by motives such as achievement of motor skills and sports goals (health, wellbeing, or aspects of social affiliation). Therefore, sports technology can be regarded as an extension of the human body and, in general, should facilitate learning processes and enjoyment of motion. Performance aspects were almost consistently rated as more important than safety aspects by both sports technology manufacturers and athletes. Experts from the scientific community and sports retailers both stated that safety, in various respects, is the most neglected topic and represents a vast field of opportunities for product design. Athletes stated that ergonomics and individualization of sports technology is an important aspect, which was not reflected in manufacturers' responses. Generally, it was striking that the statements varied considerably concerning the different aspects of investigation. Clearly, market research does not cover athletes' needs to a satisfying degree concerning the abovementioned topics.

Regarding the design of new sports technology, sports retailers stated that they have not observed considerable innovations within the last three years in the alpine ski and mountain biking sectors. The manufacturers indicated that high investment costs are the main obstacle of innovations in new technologies. Interestingly, marketing is not seen as a major barrier in terms of the realization of product novelties. This suggests that marketing budgets are adequate. To an extent, a lack of technical competence accounts for the fact that new product ideas are not realized. Lack of methods, however, was not regarded as obstacle for innovations. In contrast, the general application of basic research and design methods are scarcely used. From a purely scientific viewpoint, the knowledge required for innovation is available by conducting performance sports research and through application of underlying biomechanical methods. But the transfer to applications in leisure sports has not been successful in the past. The primary difficulty according to scientists was the challenge of accounting for the subjective emotional responses of athletes to physical product features. For instance, manufacturers stated that fun experience is a main focus in product design. This claim, though, is based on intuitive reasoning of the manufacturers.

Finally, the responses related to the potential of mechatronic sports technology were varied. To date, the only widely reported use of mechatronic sports technology used by athletes are heart rate monitors. With rare exceptions, more sophisticated applications such as motion analysis and training support have not found their way into volume markets. The main reasons are expense and poor user interface with insufficient emphasis on customer needs. The sports retailers indicated that a clear benefit for specific applications must be identified for such technology and that there should be parity between cost and performance. Also, problems in connection with power supply and protection against environmental impacts were identified by both sports retailers and athletes as core prerequisites. Usability of products is very important in the athletes' point of view. The sports technology manufacturers stated that the most promising applications refer to services in the context of their products. The manufacturers' statements generally displayed greater reluctance to innovations in mechatronics than sports retailers and athletes. This may reflect misgivings about large investments in product design, unfamiliarity with new technology and uncertain market potentials.

### 3.4.2 Focus of further research

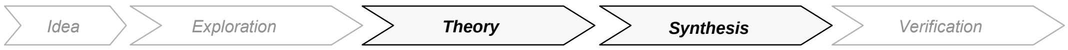
In the following chapters, an approach and its verification will be presented which focus on the quantification of a fun experience with respect to particular motion patterns and their link to product functionality. It is based on the previously presented finding that sports technology must account for the athletes' emotional background to comply with user expectations. The realization of such a connection can only be achieved in combination with detailed specifications of particular motion patterns (of a certain sport) and product functionality. The relevance of the results will be verified by means of a particular product design and evaluation.

*Table 3-19: Summary of context analysis*

*Overview about key findings from context analysis*

| | **Sport motivation (importance / ranking)** | **Sport motion (trends / characteristics)** | **Sports technology (aim / imp. prod. features)** | **Potential of mechatronics** | ***Summary*** |
|---|---|---|---|---|---|
| **Socio-cultural impacts** | • Enjoyment is driving force<br>• Display of skills -> achievement<br>• Distinction and individualization<br>• Elder generation gets more<br>• active → differentation motives | • More degrees of freedom<br>• Game-like → play with motion<br>• Rotation / acceleration → virtuosity of motion<br>• Individualization in ad-hoc groups → outdoor | • Extension of human body<br>• Means of self-realization<br>• Knowledge in performance sports<br>• Mechatronic: training support, advice | • Means of training support<br>• Advice | • *Focus on leisure and enjoyment*<br>• *Individualization in ad-hoc communities*<br>• *More outdoor sports* |
| **Science / research** | 1. Fun experience<br>2. Health<br>3. Thrill<br>4. Achievement<br>5. Socializing / wellbeing | • Thrill in motion as motivation<br>• Adaption to different types of athletes (extreme vs. relaxed)<br>• „Unsafe" situations accepted to improve motion<br>• Degrees of freedom important | • Facilitate motion for less sportive people<br>• Degrees of freedom → fun!<br>• Safe equipment important<br>• Aesthetics as attraction | • Transfer of measurement methods from science to leirue sports | • *No methods to combine instances techn. / emot.*<br>• *Biomechanics of motion not used*<br>• *Marketing often masks function* |
| **Sports technology manufacturers** | Fun experience is an important aim in design | | Alpine ski — Mountain bike<br>1. Function — Performance<br>2. Performance — Function<br>3. Optics — Optics<br>4. Safety / erg. — Safety / erg. | • Focus on services<br>• Usability / robustness<br>• Too high investments<br>• Too high product costs<br>• Medium to high potential in future | • *Investment for design hinders innovation*<br>• *Lack of know-how for high-tech applications*<br>• *Fun important, but not supported in design* |
| **Sports retailers** | 1. Fun experience<br>2. Health / wellbeing<br>3. Achievement<br>4. Thrill<br>5. Socializing | | Alpine ski — Mountain bike<br>1. Performance — Safety<br>2. Ergonomics — Ergonomics<br>3. Optics — Perf. / fct.<br>4. Fct. / safety — Optics<br>• Emotional attachment important | • Beneficial functions necessary for success<br>• Usability / robustness<br>• Self explanatory<br>• Price must be ~ 100 EUR<br>• Medium to high potential | • *Safety aspects are underestimated*<br>• *Lack of innovations*<br>• *Link between sports technology and user motivations missing* |
| **Athletes** | 1.Fun experience<br>2.Achievement<br>3.Wellbeing<br>4.Thrill<br>5.Health / socializing | | 1. Function<br>2. Performance / safety / ergon.<br>3. Optics / image / brand / techn.<br>• Means of physical exhaustion<br>• Motivating<br>• Improvement of motor skills | • Wearability important<br>• Usability / robustness<br>• Price must be ~ 120 EUR<br>• High potential | • *Link between own motivation and sports technology / functionality is not consistent* |
| ***Summary*** | • *Fun experience is a driving force in leisure sports*<br>• *Other motives (achievement, health / wellbeing) are related to fun or side effects* | • *Rotation and acceleration are important in trend sports*<br>• *Specific tease & thrill leads to attraction of a sport* | • *Facilitation of learning / motion*<br>• *Functionality is of core importance → adaption to user*<br>• *Function & performance are most important features* | • *Benefit must be obvious*<br>• *Usability / robustness !*<br>• *No complex functions*<br>• *Price 100 to 120 EUR for volume market*<br>• *Medium to high potential* | • ***Fun experience should be linked to product features***<br>• ***Safety underestimated***<br>• ***Lack of innovation***<br>• ***Pricing / investments high***<br>• ***Mechatronics as innovator*** |

# 4 Interaction of sport motive, motion task and product feature in a sport model




Some focus areas of research interest in the field of sports technology design were identified in the preceding chapter. Fun experience was identified as the major driving force in leisure sports and should be linked to product features in terms of sports technology design. To date, no approach has been developed that enables a quantitative evaluation of fun experience in the context of sports activity and sports technology. The research presented in the following chapter addresses this problem.

To accomplish this, a model that serves to identify, understand and describe the different instances of sport and their interrelations is presented. The instances of sport include specific sport motives that were discussed in the context of a certain sports motion and corresponding sports technology before (chapters 3.1, 3.2 and 3.3), as well as physical, motor and emotional aspects concerning the athlete himself.

On the basis of the theory of motivational psychology and state of the art regarding fun experience and its evaluation, a systematic approach is presented which facilitates the quantification of enjoyment and fun in a motion context. It takes into account that in the preceding chapter physical acceleration was outlined as an important element of new leisure sports.

## 4.1 The sport model as a guide in sports technology design

### 4.1.1 Background of the sport model

Psychology has developed methods to classify and quantify different motives, but the problem of operationalization in the context of sports technology remains unsolved. Which design elements are relevant aspects of motivation in sport? What are possible effects of motivation in sports technology design? How can these effects be quantified? With these questions in mind, a prescriptive model was developed to include the various aspects of the nature of sport in connection with the characteristics of sports technology. To date, no holistic perception has been created that describes the role of sports technology in the complex structure of sports activity. In competitive sports, the design of sports technology can very specifically address the needs of athletes. The efforts focus on creating the best equipment possible for an individual to be successful in competition. The main objective in the development of sports technology for competitive sports is to increase performance. However, we have seen that the focus in leisure sports is different. In leisure sports, achievement is considered an important motive to the athletes (achievement does not refer simply to the heart rate of an athlete in terms of physical performance). Other features that might contribute to enjoyment of leisure sports include the mastering of motion tasks in terms of motor skills or the use of a very lightweight and handy piece of sports technology. It was shown, however, that the emotional state "fun experience" plays a more dominant role in the context of leisure sports.

The sport model aims to describe the commonalities between these aspects, but must also serve to explain the underlying interaction mechanisms. It does not, however, claim integrity in terms of a scientifically validated model. The sport model is a pragmatic approach that originates from the combination of portions of scientific research presented earlier in this thesis. It is consequently a more auxiliary instrument intended to accommodate the findings and hence purely prescriptive.

The model is based on investigations of motivational psychology and sports science, and was developed from a leisure sports research perspective with a focus on explaining sports activity and functional aspects of sports technology. The model does not explicitly include other sport and product-related aspects such as aesthetics, which also contribute to the attractiveness of sports technology (Ebert, 2010, pp. 31ff) and sport in general. The model corresponds to the definition of sport presented in the introductory chapter of this thesis. It is limited to the essentials of sport defined in chapter 2.2.3, namely the athlete, the sport environment and sports technology, which act on the basis of the core of sport, consisting of an approved set of rules and a general understanding of the motion task. In the following sections, the instances and functional dependencies of the model will be explained.

### 4.1.2 Description of the sport model, its entities and instances

The sport model consists of two interdependent and complementary entities. The transition between these interconnected entities is smooth, but the concept serves well for a general understanding of sport and the role of sports technology (Figure 4-1). An example based on an excerpt from a typical conversation between rock climbers illustrates this concept:

"Today, I was so motivated to master the route. I already had a very good and powerful feeling on Tuesday. The movements are really awesome. On top, with Chris giving me belay and the new rope, I had enough self confidence and kept my mind free to climb the hard moves with the sloppy holds in the middle part. Unfortunately, my shoes slipped off that little ridge on the left two times. Rock was a bit slippery as well that day. But today it was real fun. I checked out my special weapon shoes and everything turned out just perfect!"

It is easy to imagine from the statements above that a variety of aspects can be traced that form a recurring theme for every sport. Because sport is exercised by athletes,

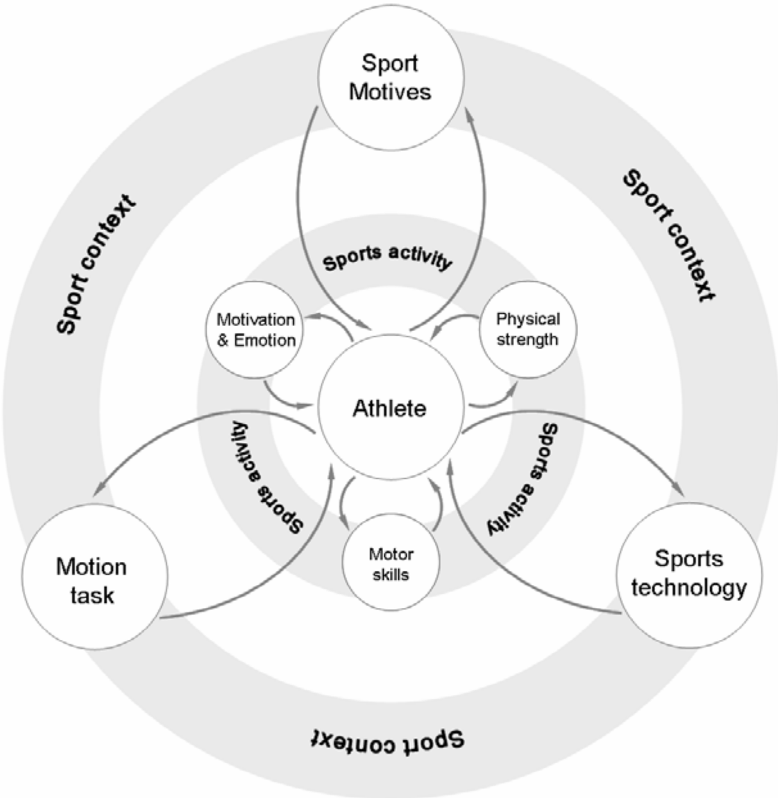



*Figure 4-1: Enhancing sport – the sport model consists of two entities which incorporate different instances. Instances, both in the sport context entity and in the sports activity entity, interact with each other (e.g. the athlete is linked to a piece of sports technology by biomechanical mechanisms). The athlete exercises in an ongoing loop of evaluating the sports activity and the sport context.*

the individual is always the initial focus of the activities. Elements such as the challenges of the climbing route (motion task), sports technology (climbing shoes, rope, gear) and the climber's will to master the route (achievement motive) are accompanied by statements about the activity itself: hard moves, slipping off ridges, powerful feeling, state of mind and enjoyment of moves. Based on this description, the two entities of the sport model, sport context and sports activity, will be explained.

The sport context entity:

Sport context here contains prerequisites that form the necessary environment and incentive for the execution of a certain sports activity. In a basic sense, motives can be regarded as goals of potential activities. Examples of motives in the context of sport are achievement, physical activity and enjoyment. Motives are activated by attractions which are formed by situational conditions. The latent desire for a goal-oriented activity is thus termed motivation. In general, science agrees that motivation accounts for any deliberate activity of the human being and by extension, sports activity. As discussed below, a particular form of motivation that evolves from pure activity itself is especially relevant.

An individual needs to understand how to perform a specific sport to be able to master the associated challenges (e.g., ski a slope, climb a wall, surf a wave or skate a ramp). Thus, the motion task implies a set of rules in a broader sense, either in terms of rules for motion patterns, of boundary conditions for the execution of a certain sport, or both. The motion task can vary considerably between different sports. For example, the only rule for a sprinter is to run as fast as possible, while a soccer game consists of a more complex set of rules, and a new trick on a skateboard is bound only to the obvious rule that the trick must be done with a skateboard.

In many sports, such as skiing or cycling, sports technology is metaphorically the mechanical extension of the athlete's body and thus, represents crucial attributes of the attractiveness of the sport. Ebert explicitly defined attractiveness of sports technology in addition to the motion task and the environment to describe the attractiveness of sports activity (Ebert, 2010). In most instances some kind of sports technology is needed, whether as a means to an end, as support or as protection for the athlete. In cycling, for instance, a bicycle is clearly a necessary piece of equipment while a bicycle helmet is a secondary object to enhance safety.

In addition to motive, motion task and sports technology, an environment is required in which a specific sport can be performed. This environment can consist of a sports hall, a street, rocks, water or other media which are lawful and suitable for carrying out the sport.

The sports activity entity:

The sport model's second entity refers to the act of exercising. We will see in the next chapter that individual motives can be increased, for instance, by an elusive motion task and a useful piece of sports technology (sport context). This is referred to as "motivation" in psychology. As soon as individual motives are triggered (for example, a cyclist has interest in mountain biking and has a mountain bike at hand) the sports activity is likely to take place. When going uphill, both the cyclist's mental state (motivation) and physical strength (e.g., cardiovascular condition) will be tested. On the downhill run, other aspects such as motion technique and reaction time (sensomotoric skills) gain importance. In every case, the cyclist will be led by emotions in the course of the activity. He will probably experience fun, fear or vigilance.

### 4.1.3 Interactions between the instances of the sport model

Emotions can be regarded as control parameters for sports activity. Emotions, together with sensomotorics, account for the guidance through sports motions, essentially representing a motion control loop. In fact, other than sensomotorics, emotions play a role in two respects. In the microcosm of sports activity, emotions account for real-time evaluation of the situation. In situations with intense positive emotions (such as during a very nice passage of the cyclist's downhill run) the balance of body and mind is referred to as "flow experience" by researchers. Flow refers to total concentration and commitment to the activity. In the macrocosm of sport, between periods of actively participating in sporting activities the cyclist (in this example) will perhaps feel satisfied with his performance. But the emotions will also cause the cyclist to verify his achievement and readjust his goals. Can I improve my performance? Can I go for a more difficult downhill run? Wouldn't the new adjustable damping system facilitate tricky downhill passages? Such questions already express activation of new motivation.

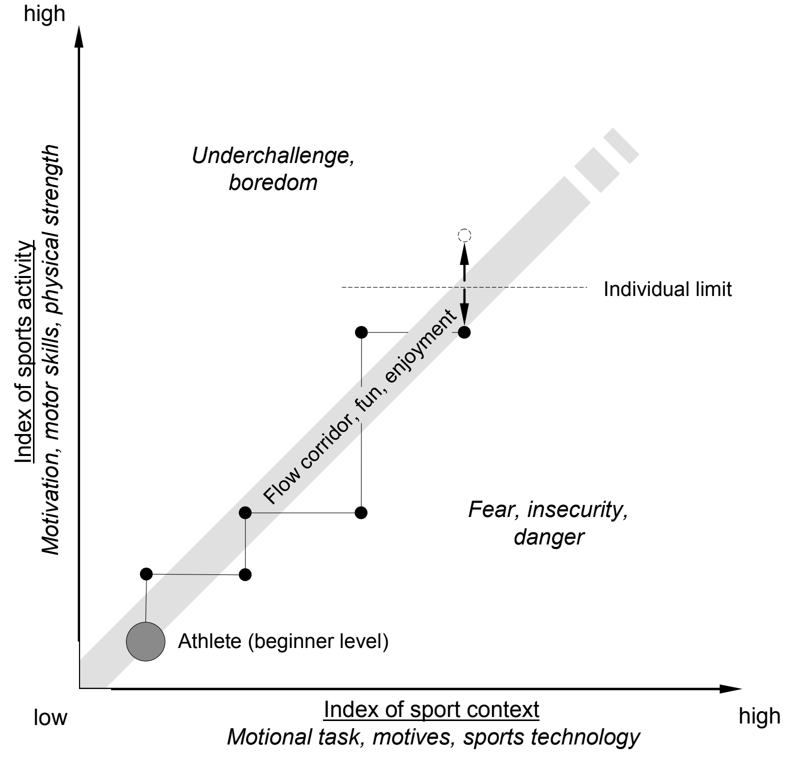



*Figure 4-2: Fun experience and enjoyment in sports activity with respect to the learning process (motor skills) and physical improvement. Positive emotions can be experienced in a hybrid balance between the index of sports activity (individual skills) and the index of sport context (challenges). Each athlete will face an individual limit which corresponds to his personal skills (modified from Csikszentmihalyi, 1990).*

The concept of the presented model describes iterative loops enclosing the instances of the sport context and the sports activity. These instances are evaluated and weighted by the individual, both during and following the course of activity.

One of the most important mechanisms in exercising sport is learning processes and physical strength training. The model loops are applicable regardless of an athletes' skill and physical state levels. Beginners start learning basic motion patterns which eventually are subsequently improved and stabilized (Meinel & Schnabel, 2006, pp. 146ff). In the same course, they will improve their physical strength implicitly or by applying systematic training methods. These processes are accounted for in the instances and interaction loops which were described above. A positive effect of enjoyment and fun experience is observed when the particular elements form a synergistic balance. The cyclist, for example, will not feel comfortable on tracks which he is not able to master. Figure 4-2 depicts a modified version of Csikszentmihalyi's (1990) model that serves to explain the mechanism of learning and training in sport. As soon as an individual's limits are exceeded, the athlete will feel uncomfortable, in danger or insecure, leading to a readjustment of the sport context. For instance, the cyclist will likely choose easier tracks to improve his cycling technique before he faces more sophisticated challenges. The opposite is also true: if the challenges can be mastered too easily, the athlete will be under challenged and likely experience boredom, necessitating an intensification of the challenges. Figure 4-2 also illustrates that at some point, each athlete will reach his individual limit as defined by talent and physical conditions.

### 4.1.4 Related work and relevance for sports technology design

Thus far we have discussed the commonalities between different instances of the sport context and sports activity. The sport model can serve as an abstract guide in sports technology design with respect to the clarification of the design focus. Before considering a design example to demonstrate the benefit of the sport model, a summary of previous systematic approaches for different aspects of sports technology design is presented.

Various triggers can inspire sports technology design: we have seen before that ideas often evolve from sport sub-cultures, mostly youth driven. The mountain bike, for example, was invented because Gary Fisher, Joe Breeze and Charles Kelly were frustrated with bicycle road races and began riding 40-year-old cruiser bicycles on the 850m downhill track of Mount Tamalpais, California, in 1973 – just to have fun and to try something new. Another design route is the systematic optimization of existing products and design projects initiated by a sports equipment manufacturer. Indeed, many of the newer trend sports of the last decades began as sub-cultural "spin-offs" and were industrialized to make them accessible on a larger scale – mountain bikes and inline-skates are good examples. Lamprecht et al. (2003) stated that the process of commercialization remains the same, independent from the character of the sport. In established sports, athletes frequently contribute to development. Tinz investigated the role of lead-users for the design of sports technology in an industrial environment and found that the contribution of athletes to product design occurs primarily in the task clarification and evaluation phases (Tinz, 2007). Sports science and scientific research in sports technology can also represent sources for new or optimized designs. Senner (2001) developed a pool of biomechanical methods, embedded in the systematic design approach of Ehrlenspiel (2007), which can be used in sports technology design. Senner's approach and the presented methods are particularly applicable when physical interactions between the athlete and a piece of sports technology must be clarified. Odenwald (2006) discussed the applicability of biomechanical and engineering methods in the design process. The biomechanical context is strongly related to the functionality of sports technology. Ebert (2010) defined functionality as an entity of weighted product characteristics and further presented a method which could be used to construct a functionality index for sports technology, facilitating objective evaluation and comparison. Ebert's model also combines a wider range of aspects as input parameters for product design which was not explicitly discussed before, and can help in quantifying the different instances of the sport model presented in this research once the importance of these instances is clarified.

Moritz (2008) has developed an approach which describes how inventions can be categorized. It focuses on the generation of new concepts. In engineering design, a variety of publications are available that support the various phases of product design in terms of systematic approaches: task clarification, conceptual design, embodiment design and evaluation (Ehrlenspiel, 2007; Lindemann, 2007; Ponn & Lindemann, 2007; Pahl et al., 2007; among others).

In addition to the technological view, basic literature from the fields of sports science and human science that addresses motion tasks as they relate to learning processes and motor skills (Meinel & Schnabel, 1998) will be reviewed. This will provide support in study design and statistics (Bortz & Döring, 2006; Bühner & Ziegler, 2009) and support the understanding and research in training science (Weineck, 2004).

The contributions of motivational psychology to the field of sport will be discussed in detail in subsequent sections. They provide the theoretical basis for the implementation of an approach, aiming for quantification of athletes' motivation and their impact on sports technology design. The latter has not been addressed in scientific research thus far.

Figure 4-3 depicts the contributions of the previously discussed disciplines to the understanding of sport.

The following example describes one of the possible paths in the sport model to clarify design tasks. The idea was to develop an additional training accessory that could be attached to stationary spinning-bikes to facilitate dynamic tilting of the spinning-bike. A survey among athletes engaged in cycling and spinning-training revealed that such a device would satisfy a demand for a more realistic sensation of cycling. Dynamic tilting is common in road cycling when the cyclist elevates from the fixed saddle position to utilize his body weight for additional pedaling power. Figure 4-4 (left) depicts a tilting position on a normal bicycle. The body is shifted opposite to the tilted bicycle to maintain dynamic equilibrium. In contrast, spinning-bikes are stationary and cannot replicate this maneuver. On these spinning bikes, a heavy flywheel (m = 30 kg) is pedaled which supports a smooth pedaling frequency.

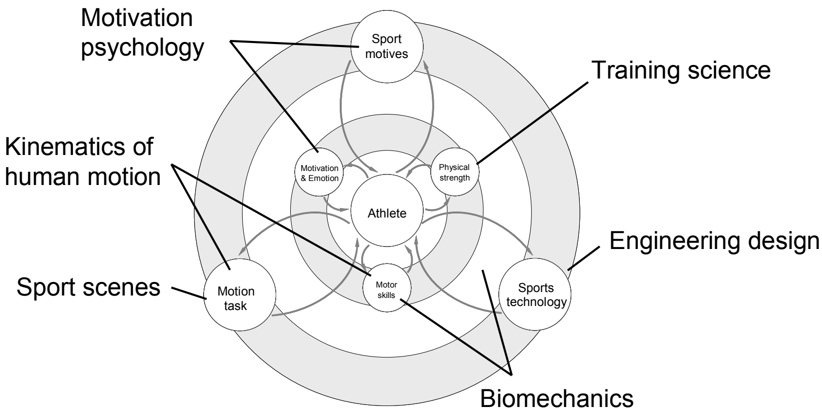



*Figure 4-3: The sport model in the context of different disciplines which contribute to the understanding of sport and sports technology design approaches.*

As a first attempt, a training device was designed that consisted of an additional frame to fix the spinning-bike on a fulcrum slightly elevated from the ground (see Figure 4-4, middle). Motion analysis during testing along with subjective impressions revealed some severe deficiencies (Meier, 2005):

- The spinning-bike was unstable. A shaky feeling was observed during cycling.
- Because of the high position of the fulcrum, the heavy freewheel produced an immense reset moment which made it nearly impossible to tilt the spinning-bike. This resulted in athletes applying the opposite motion from what was intended, utilizing the complete body weight to shift the bike sideways.
- The tilting of the spinning bike caused tedious strain on the arms. In road cycling, minimal effort is needed for the tilting of the bicycle.
- Poor physiological cycling was suspected because of pain in the knees.

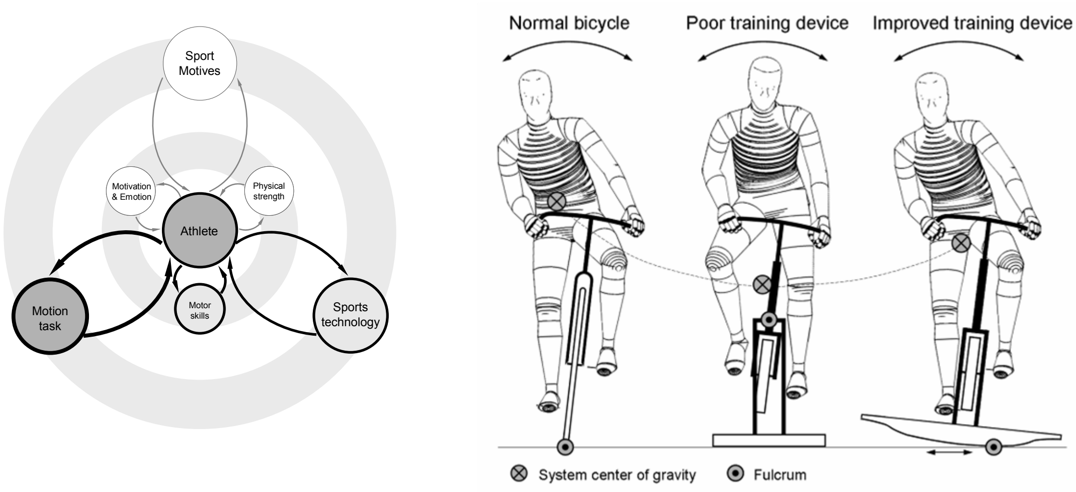



*Figure 4-4: Design example spinning-bike: enhanced training was realized by developing rolling skids which can be mounted to standard spinning-bikes (right). Therefore, a dynamic bending of the spinning-bike, similar to road bicycles (left), is possible (Ramml, 2009). The first design (middle) revealed severe deficiencies in usability and safety because of poor clarification of the underlying motion patterns (see highlighted areas of the sport model on the left).*

The cause of failure lay in the fact that the biomechanical principles of cycling, in combination with the motor skills of the athletes, were not sufficiently clarified beforehand (see Figure 4-4, left, for the localization of these instances in the sport model). Proper function clearly could not be achieved and testers reported feeling anxious because of the unfamiliar kinematics and the shaky feeling.

Two students followed up in a design project with the purpose of developing an appropriate training device (Gerber, 2009; Ramml, 2009). The first step was to investigate the kinematics of cycling on stationary spinning-bikes. A simulation model of the spinning-bike and a simplified cyclist was developed to analyze different solutions and to perform optimization routines.

The main goal of the design project was to lower the fulcrum axis such that a more realistic feeling in tilting of the spinning bike would be achieved. A simple solution was implemented, similar to the principle of a rocking horse: two curved skids were mounted to the frame of the spinning-bike (see Figure 4-4, right). Simulations showed that a more realistic tilting feeling could be achieved with this setup, despite the fact that (unlike road cycles) the fulcrum axis shifts from left to right during tilting (Figure 4-5).

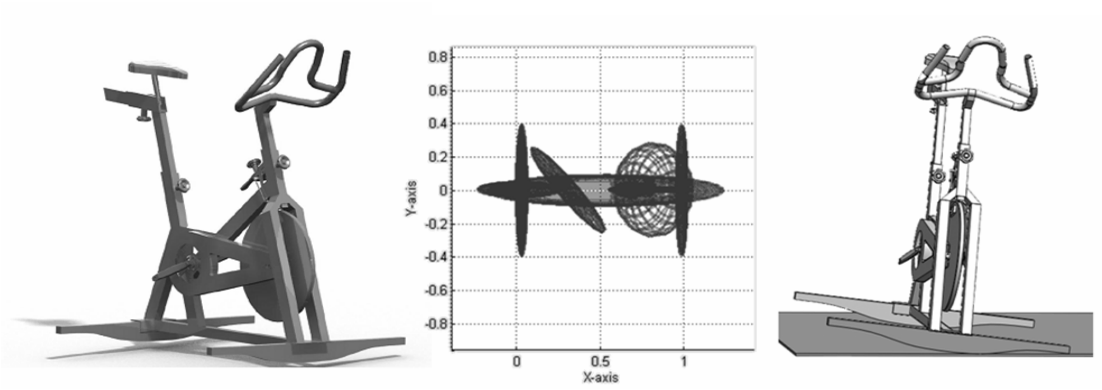



*Figure 4-5: CAD-model of the spinning-bike including the rolling skids mounted to the bottom of the frame (left). A simulation model served to clarify kinetics and kinematics of different solution during cycling (mass distribution of the spinning-bike and CAD-model in the simulation tool, middle and right).*

A prototype was built and evaluated by participants in spinning-cycle lessons. The participants of the evaluation session were enthusiastic about the additional degree of freedom. The outcomes showed that this response was because of increased enjoyment, not the opportunity to train in a way similar to road bicycles. This fact, however, could not be quantified in the study. The following sections present an approach that aims to provide such quantification.

In this example, the sport model conveyed the awareness of the underlying motion task and specified the requirements of the design. In general, all instances of the sport model should be considered to specify their importance and influence. In a particular design, some instances are usually focused on and substantiated in terms of utilizing appropriate methods and tools. An application example in which the various instances are addressed will be presented at the end of this thesis.

## 4.2 Importance of motivation and emotion in sports technology

Because the presented research aims to take advantage of the connection between sport motives and emotional experiences in sport for its utilization in sports technology design, it is essential to understand the principles behind this concept. Therefore, a brief summary of the theoretical background in motivational psychology is given. This background is followed by a summary of current scientific understanding of fun experience.

### 4.2.1 Theoretical background: motivation

*Term description*

**Motive**

Motives are individual and constant personality traits that can be regarded as wirkvalues guiding human action (Schneider & Schmalt, 2000; Kuhl, 2001; Rheinberg, 2004), likewise defined as classes of activity goals that comprise a certain group of objectives (Vroom, 1964; Heckhausen, 1989).

The term ‘motive’ is one of the central constructs in behavioral psychology, the driving force behind every conscious human action. Therefore, the incitement of sports activity can be explained in the context of motivational psychology. The goal of motivational psychology is the explanation of human behavior concerning the aim, the constancy and the intensity of certain activities. In particular, the differences in behavior of people as well as continuity and change of behavioral aspects are subjects of research (Rheinberg, 2000, pp. 11ff). The main variables of interest are the aspired target state of an activity and the degree of attraction.

What motivation means:

Motivation is a hypothetical construct. Motivation is not a homogeneous unity and no manifestation of cells in terms of a motivation muscle (Rheinberg 2000, p. 15). In fact, motivation is an abstract term relating to activities of daily living that are goal-oriented. Geen (1994) defined motivation as “referring to the initiation, direction, intensity and persistence of human behavior”. Generally, most definitions of motivation include the idea of an activating orientation of current situations in daily activities towards goals with positive attributes. It is noteworthy that in classical

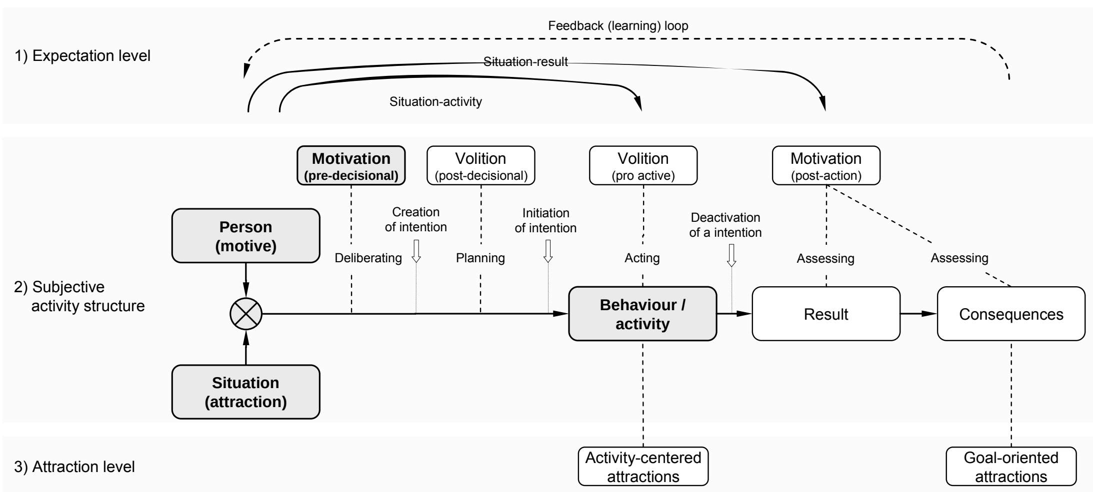



*Figure 4-6: The cognitive model of motivation (according to Heckhausen, 2006, p. 7 and Rheinberg, 2000, p. 70).*

motivational psychology, 'motivation' is distinguished from the term 'motive' (elements highlighted grey in Figure 4-6).

According to Heckhausen and Heckhausen (2006), motives are relatively stable dispositions of the human character and describe the individual importance of a specific set of goals. However, the occurrence of specific motives appears to depend on genetics and early childhood experiences (also Winterbottom, 1958; Meyer, 1973; Trudewind, 1975; Veroff, 1965; Heckhausen & Roelofsen, 1962).

Important sport motives:

The most important types of motives include achievement motives, social affiliation motives and motives that influence willpower (Heckhausen, 1989; Reiss, 2000). Physical activity and safety motives are also frequently identified as important types. Some specific sport motives are listed in unpublished lecture notes of the University of Salzburg, Austria; others were found in other publications (e.g. Rheinberg, 1989). Gabler and Nagel (2001) and Gabler (2006) list a number of specific sports motives in descending order of importance as follows: fun, enjoyment of motion, wellbeing, relaxation, fitness, health, attractiveness of a sport, open air, physical strain, nature, body, improvement of skills, some motives of social affiliation, competition and thrill. The order of importance of the specific motives listed above agrees well with the results of the surveys presented in chapter 3 (Table 4-1). The similarity between these two independent studies suggests a high degree of validity in the reported importance of these sport motives.

*Table 4-1: Comparison of importance of sport motives from the survey conducted as part of this work and a review of available literature*

| *Sport motives, own survey* | | *Sport motives, findings from literature* |
|---|---|---|
| Fun experience | ↔ | Intrinsic pleasure, entertainment |
| Health | ↔ | Fitness, health |
| Wellbeing | ↔ | Balance, catharsis, relaxation |
| Performance | ↔ | Achievement, success |
| Thrill | ↔ | Excitement |
| Socializing | ↔ | Social relationships |
| | | Autonomy, self-determination |
| | | Self-expression |

How motivation is activated:

According to the model depicted in Figure 4-6, an attraction is formed by situational aspects such as motion challenge, the environment and sports technology, resulting in the activation of a motive. For example, a skier facing a deep powder mountain side will feel an attraction. At that moment, individual motives develop from latently present situational attractions to the construct motivation, ultimately leading to a certain behavior or activity. The skier may decide to attempt the downhill either for the sense of achievement or simply for enjoyment. Both scenarios will be discussed below. It is evident that the process of motivation must be connected to a control instance of some kind. Heckhausen (2006) accounted for this fact in the enhanced cognitive motivation model and envisioned post-activity evaluation processes (parts highlighted white in Figure 4-6). The evaluation processes are part of the sport motivation model and can act as amplification or attenuation of motivation by reviewing achievement of goals or the memorization of emotional aspects.

The Arousal Theory should be briefly discussed because it is an important concept in understanding why people form different individual impressions during a sport experience. Walter (2005) states that the theory distinguishes between extraverted and introverted people based on the level of arousal of the neocortex, a part of the cerebrum. By nature, introverted people are on a higher excitement level than extraverted people. Scientists assume that humans strive for individually comfortable levels of arousal and that an ideal level of excitement leads to a maximum amount of achievement possible in a specified activity. Extraverted people constantly need additional stimulation to obtain their ideal level of arousal and in general are more active and venturesome (Eyseneck, 1976, p. 22). In sport, these people tend to be involved in activities with a higher risk or thrill potential, such as climbing, freeriding or kite-surfing.

Distinction of needs and motives:

The presented definition of motivation implies voluntary behavior instead of behavior related to reflexes, instincts and other biologically controlled processes. Maslow (1943) was one of the first people to distinguish between “lower” biological or instinctive needs (such as hunger) and “higher” or deliberate needs (such as self-esteem or self-fulfillment) for which the term ‘motive’ is applicable. A clear distinction between deliberate and instinctive behavior, however, is not possible (Rudolph, 2003, p. 5). In developed societies, the lower physiological needs such as hunger and safety are typically satisfied, whereas satisfaction of higher physiological needs such as esteem and self-actualization still require self-controlled and self-determined, namely motivated, activity. This concept of motivated activity seems highly applicable when considering the history of leisure sports. Leisure sports originated during a period of intellectual emancipation and were propelled by side-effects of the industrial revolution and the so-called service society: namely division of work, improved standard of living and increased amounts of free-time (but also greater specialization of work). Finally, activities such as sport always require volition and awareness whereas so-called “implicit” motives normally remain unconscious and unconsidered. Maslow’s basic needs are predominantly implicit motives. Explicit motives are based on cognition and self-reflexion.

The so-called achievement motive is of specific importance for the discussion of motivation in the context of sport. Various authors have discussed the role of achievements in sport (Rheinberg, 2006, for instance). Achievements are the basis for understanding the difference between goal-oriented and activity-centered motivation; this difference is central to the focus of this work. The term achievement, however, is somewhat ambiguous in its use in everyday speech. Clarification of this term follows below.

### 4.2.2 The achievement motive

Atkinson's (1957) work on the dynamics of personality advanced the achievement motive to overcome the former drive theories (e.g. Freud, 1961). Formerly, Murray was a proponent of the achievement motive and wrote of its appeal: "To accomplish something difficult. To master, manipulate or organize physical objects, human beings, or ideas. To do this as rapidly and as independently as possible. To overcome obstacles and attain a high standard. To excel one's self. To rival and surpass others. To increase self-regard by the successful exercise of talent." (Murray, 1938, p.164). Several of these statements are similar to attributes that were discussed regarding the definition of sport: to master tasks, feel speed, experience challenge and competition with other people and enhance self-fulfillment.

Distinction of the achievement motive:

In contrast to words such as effort, striving or diligence which are synonymously used in everyday speech, the term achievement is used in a different sense in motivational psychology. Specifically, not every activity done with effort or diligence is considered a motivated activity. For instance, activities that are obligatory or promote personal well-being do not fit the idea of achievements. Only behavior or activities that are specifically directed at self-evaluation of one's personal capabilities with respect to a certain standard are regarded as motivated in the sense of achievement. The attraction in these circumstances is that the standard can be achieved or even surpassed. For example, many cyclists envision crossing the Alps by bicycle within a specified time period, such as eight days. Although the goal of crossing the Alps is itself a great challenge and successful completion will bring a sense of fulfillment, the cyclist will gain even more satisfaction if the venture can be complete in fewer than the planned eight days. The essential part of the attraction is the achievement of the objective itself and the result is self-contentment. It is important to recognize that self-contentment can only result from achievements of an individual and not from positive outcomes that may occur by coincidence.

Individual perception of achievements:

Atkinson (1957) introduced motivational determinants of risk-taking behavior that are based on the assumption that the subjective judgement of success influences the choice of a task selected by a person from a variety of tasks of different aspiration levels. In the case of sport, this means that the more complicated the task, the greater the appeal to master the task. Atkinson (1957) developed tests to quantify achievement motivation based on the Thematic Apperception Test (abbreviation: TAT, also see (Schultheiss, 2001). Differences between outcome expectation and self-efficacy expectation need to be discussed (Bandura, 1977). Outcome expectation is the estimation by an athlete of whether a goal can be achieved through a certain sequence of motions while self-efficacy expectation refers to the self-evaluation of an individual's skills and evaluation of whether the task can be mastered by means of those skills (Figure 4-6). Most people, especially the highly motivated, are able to competently estimate their capabilities and tend to choose a level of activity that fits their skill set, while less motivated people tend to set unrealistic goals (Rheinberg, 2000, p. 71).

### 4.2.3 Activity-centered motivation and fun as driving forces in sport

The preceding section discussed that sports activity is dependent on motivation. The sport context must produce enough attraction to trigger activity. It was also discussed that the goal-oriented nature of motives is characteristic and that the achievement motive is particularly outstanding. To understand the strong emphasis on fun-oriented motives in sport reported in the athlete survey (chapter 3.3) and other sources (e.g. Moritz & Steffen, 2003), it is necessary to highlight the activity-centered understanding of motivation.

The ambivalence of goal-oriented and activity-centered motivation:

The original cognitive motivation model is not suitable to explain the concept of activity-orientation because it assumes cognitive processes, and therefore a strictly rational purpose-orientation, are required for motivated activity. For example, the analysis of free-time behavior has shown that approximately 48% of daily activities do not explicitly aim to achieve a certain goal (Csikzsentmihalyi, 1975; Rheinberg, 1987; Rheinberg, 1989, p. 125). In fact, the authors identified activities for which the source of gratification was in performing the activity itself.

Apter (1982) differentiates these initially contrary concepts as telic and paratelic (or autotelic) motivations. An autotelic state of mind refers to the mental attitude of an individual who seeks pleasure and excitement, and has a fun loving attitude towards a defined activity. Examples for autotelic motives are activity orientation, pleasure and thrill. Most sport activities encompass parts of both telic and autotelic concepts of motivation such that a definitive separation of activities by motivation type is not possible. During a mountain bike tour, for example, the ride is often composed of both an enjoyable downhill portion and a more goal-oriented uphill climb. The response to these sections with different motivation types depends on the personal characteristics of the athlete. Heckhausen's cognitive motivation model can be extended to account for the different characteristics of motivation (Figure 4-6). This refers to the nature of the attraction of latent activity alternatives and to the modes of expectation that were discussed above (according to Rheinberg, 1989, p. 104). However, while activity-centered action shall only be carried out for the sake of itself, it can be assumed that every sports action is goal-drive or driven by a certain extent of termination. In the following, this conflict will be discussed.

Emotions and flow in leisure sports:

In the explanation of goal-oriented and activity-centered motivation, two terms are widely used: intrinsic and extrinsic motivation. Rheinberg (2000, pp. 145ff) illustrates the challenge encountered in defining these terms by referencing their varied use in literature. The difficulty lies in the fact that the terms are used somewhat inconsistently and loosely with respect to their literal definitions. The only common denominator seems to be that intrinsic motivation somehow refers to "coming from within". For describing motivation in the context of serves, a specific class of motives called dynamic joys (Duncker, 1949) may be more appropriate. Duncker's concept outlines the necessity of goals for any activity, in the case of dynamics joys with the only purpose to experience the thrill of enjoyment in the course of activity and until the achievement of the goals. Besides enjoyment and fun as emotional counterparts to activity-centered motivation, an even stronger emotional state – the flow experience – was defined by Csikszentmihalyi (1975). Prior to discussing flow experience in greater detail, a general definition of what is meant by 'emotion' may be helpful.

*Definition*

**Emotion**

Emotion (lat.: ex „out" and motio „motion, arousal") is a psychophysiological process that is activated by conscious and/or uncoscious appreception and interpretation of an object, situation or activity and goes along with specific cognitions, physiological changes, individual feelings and a change of disposition of behaviours.

Any consideration of the importance of positive emotions in human psychology begins with the concept of hedonism, or the Pleasure-Pain Principle, which was initially established by the ancient philosopher Epicur. The principle assumes that all human activity is based on the principle of maximizing pleasure and minimizing pain (Rudolph, 2003, p. 2) which corresponds to motives of desire, called appetence, and avoidance, called aversion, respectively (Heckhausen, 1977, p. 175). Although this principle is controversial, it is a good starting point to understand the link between motivation and emotion in the context of sport.

Control mechanisms in human psyche have evolved to check the degree of satisfaction of motives of a certain action compared to goals established at the start of the activity (Heckhausen, 2006, p. 60). In addition to rational considerations, emotions play a very important role with respect to sport motivation.

Emotions can be regarded as an organ of mental cognition (Bischof, 1993), signifying the degree of satisfaction of motives and therefore acting as an adjustment tool to help navigate through the choice of potential actions in sport (according to Damasio, 2000). In dangerous and unexpected situations such as a fall during skiing, we would experience a mixture of surprise and fear, immediately activating previously stored motion engrams in our brain to avoid the fall or reduce injuries. In contrast, the skier will likely experience a sense of enjoyment during the downhill ride. The example demonstrates that emotions incorporate both cognitive and physiological components. This suggests that the person experiencing emotions in the course of a specific action, the downhill ride for instance, will adapt cognitions that value this action (e.g. comparison to a previous anticipation of danger), recognize physical changes (e.g. muscular tension, higher pulse), experience an identifiable feeling (e.g. happiness) and often exhibit similar behavior in the future. For instance, after a successful downhill ride, the skier will be motivated to face similar challenges. Thus, established emotions are different from feelings.

Because emotions are connected to the evaluation phase of an activity, they act as a kind of superordinate gratification or punishment. Yet the anticipation of an emotion can create motivation. In contrast to emotions, rational considerations are intentional. According to Bischof (1993), rational answers can impede quick reaction times whereas emotions can be regarded as a prerational recognition organ to accelerate action. Darwin (1872) established a list of eight basic emotions. Especially the intensity of emotions has since evolved. Plutchik (1962) developed a comprehensible model of emotions opposing the different basic emotions and their differentiation regarding intensity (Figure 4-7).

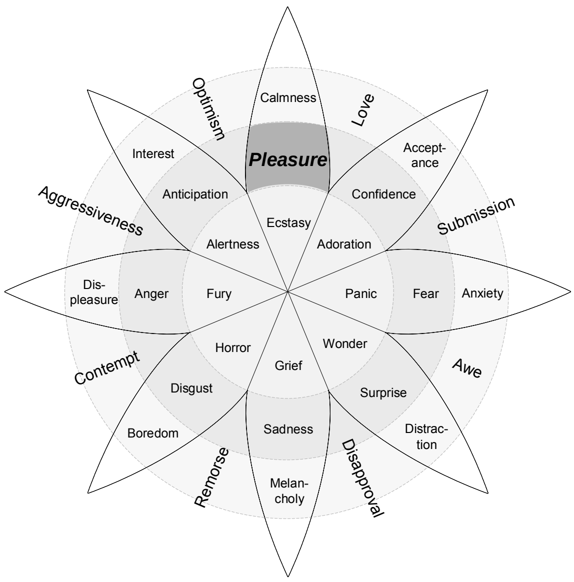



*Figure 4-7: Emotions (according to Plutchik, 1962) with areas of focus for the present work highlighted.*

Csikszentmihalyi (1993) defined the emotional state of “flow” as an intensification of enjoyment or fun. Flow occurs when our physical or mental capacities are stretched to their limits in pursuit of a worthwhile goal. In fact, just about any activity can be made autotelic in the sense of flow. Flow is not something that happens to an individual, but something an individual makes happen. It is not dependent on external events, it is the result of one's ability to focus, and thus give order to consciousness. Enjoyment and fun, however, are core elements of the flow experience. To some extent, flow is the exaggeration of enjoyment and therefore an important emotional concept in the context of fun. Without elaborating on the specific details of the numerous studies in connection with flow, the basic elements are explained in the following list (Table 4-2).

*Table 4-2: Elements of the "flow experience" (according to Csikszentmihalyi 1993)*

| *The core elements of Flow* |
|---|
| 1. *Clear goals* (expectations and rules are discernible and goals are attainable and align appropriately with one's skill set and abilities). Moreover, the challenge level and skill level should both be high. |
| 2. *Concentrating and focusing*, a high degree of concentration on a limited field of attention (a person engaged in the activity will have the opportunity to focus and to delve deeply into it). |
| 3. *A loss of the feeling of self-consciousness*, the merging of action and awareness. |
| 4. *Distorted sense of time*, one's subjective experience of time is altered. |
| 5. Direct and immediate *feedback* (successes and failures in the course of the activity are apparent, so that behavior can be adjusted as needed). |
| 6. *Balance between ability level and challenge* (the activity is neither too easy nor too difficult). |
| 7. A sense of personal control over the situation or activity. |
| 8. The activity is *intrinsically rewarding*, so there is an effortlessness of action. |
| 9. People become absorbed in their activity, and focus of awareness is narrowed down to the activity itself, *action awareness merging*. |

In the previous chapters, it was shown that fun experience, and even flow experience, plays an important role in leisure sports. Interestingly, all age groups surveyed for the present work identified the fun motive as the main driving factor for sports activity. On the other hand, the interviews with sports retailers revealed that a great difference can be observed in the individual's comprehension of risk and thrill. The motives and emotions mentioned above underlie dispositions in the character of the athlete. The affinity towards risk and thrill can be an important parameter for the estimation of a "fun factor" in sports. The concept of "sensation seeking" provides methodical support to distinguish the different dispositions of a personality (Zuckermann, 1979; Zuckermann, 1984).

First, the theoretical understanding of motivational mechanisms in sport as outlined in previous chapters served as a basis in the development of the sport model presented at te beginning of this chapter. The model aims to provide a descriptive approach on how functional aspects of sport can be embedded in a comprehensive cause-and-effect structure of sports activity. Further, the results serve for an approach to the creation and evaluation of sports technology with regard to emotional experience during sports activity (see subsequent chapters).

## 4.3 Related work on fun experience in sport

The preceding section clarified the behavioral mechanisms of motivations and emotions. We saw that emotions such as fun and enjoyment in the context of sport can only evolve from a mixture of motion tasks, individual motives and their conjunction with the corresponding environment and sports technology. The results clearly show that “fun” is a motive and “fun experience” describes for the dedicated emotion which can be achieved from exercising. The goal of the present research is to go one step further and develop an approach which serves to quantify fun experience. This will be achieved in terms of parameters that can be utilized as input for sports technology design. To accomplish this, it is necessary to understand which situational aspects influence and trigger fun experience and what attempts have previously been undertaken to measure fun experience. In creating an approach for systematic evaluation, it will also be helpful to look at adjacent or similar emotions (synonyms). These similar emotions might serve as auxiliary material to circumscribe the construct “fun experience” and therefore enhance the evaluation of it. Finally, to confine the construct, existing definitions shall be considered.

A variety of aspects may influence fun experience in a sport reality. The abovementioned fields of research for related work contribute to these aspects and form an understanding of the construct fun experience. The following figure depicts possible influencing factors which shall be specified in the research (Figure 4-8).

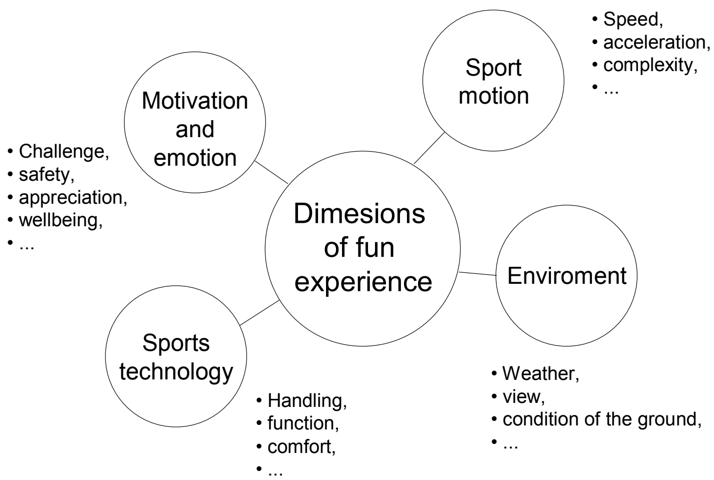



*Figure 4-8: Different dimensions of fun experience. A variety of aspects can be source of fun experience in a sport context. In the presented research, in specific the influence of sport motion and motivation and emotion on fun experience will be elaborated. The situational view is connected to the use of a certain piece of sports technology (e.g. bicycle).*

### 4.3.1 Factors influencing fun experience

Little information is available about the influence of different aspects on fun experience during exercising sport. As demonstrated below, there have been many efforts to describe fun, but few efforts to quantitatively evaluate it, particularly in the context of sport and sports technology. Moritz and Steffen (2003) presented a study of fun experience for a user-oriented testing procedure. They qualitatively evaluated emotions of athletes after they had used certain pieces of sports technology. They stated that fun is characterized by action, enjoyment and relaxation. Fun experience was described by the participants to be achieved in the following situations:

- The possibility of using extraordinarily attractive sports technology.
- Sensation of forces and accelerations (centrifugal forces).
- The mastering of a challenging motion task, moving in accordance of challenge and skills.
- The experience of competence in controlling or dominating a piece of sports technology or the environmental conditions.
- The experience of success in terms of self-affirmation.
- The experience of aesthetics of motion.
- The possibility for creativity in terms of creating new motion experiences.

It was also noted that weather conditions and the surrounding environment play an important role in experiencing fun and enjoyment. The present research concentrates on the motion related aspects of fun experience. The above statements also specify that the interaction between the athlete and a piece of sports technology is crucial in the development of strong emotions. But this interaction is inherent to certain types of motion and the individual motor skills. Motion types arousing emotions such as fun experience are subject to individual preferences. The sensation of external forces, for instance, is a recurring element of fun experience in terms of autotelic enjoyment. This was a starting point for the research presented in the subsequent chapter.

### 4.3.2 Methods for the evaluation of fun experience

Several scientific studies provide information about the evaluation of fun experience. The study by Moritz and Steffen aimed for evaluation, but was limited to qualitative analysis. Kendzierski and DeCarlo (1991) developed a questionnaire to evaluate fun experience quantitatively and devised a “fun factor”, termed PHYSICAL ACTIVITY ENJOYMENT SCALE (PACES). Unfortunately, the evaluation was conducted indoors in a relatively static activity which limited its external validity. However, parts of the questionnaire used in the study were modified and used in the development of the evaluation questionnaire presented in the subsequent chapter. Some items from the factor analysis of the questionnaire POSITIVE AFFECT NEGATIVE AFFECT SCHEDULE (PANAS, see Crocker et al., 1995) were also used in developing the questionnaire.

### 4.3.3 Definitions of fun experience and synonyms

Fun experience is described as the emotional reaction to the incidence of a desired event, consciously or unconsciously (Sulz & Sulz, 2005, p. 26). Kimieck and Harris (1996) published an overview about existing definitions and notions of fun experience and some synonyms. Two major characteristics contribute to the definition: fun experience is a positive emotional state and it is the response to some activity or state which satisfies individual motives. Such, for the design of the following study, questions should be created that address aspects of this state in multiple ways to increase the validity of the evaluation method. Further, the emotional state must be evaluated either during or immediately following the sports activity. Because emotion is a direct response to the activity, the awareness of the emotional state would diminish with time following completion of the activity. For reference, Table 4-3: Literature findings concerning the definition of fun and related constructs.

*Table 4-3: Literature findings concerning the definition of fun and related constructs*

| *Author(s)* | *Construct* | *Definition / description* |
|---|---|---|
| CSIKSZENTMIHALYI 1990 | Fun experience | Enjoyment as “flow”: "enjoyable events occur when a person has not only met some prior expectations or satified a need or a desire but also gone beyond what she or he has been programmend to do and achieved something unexpected, perhaps something even unimagined before... An enjoyable activity is one that is done not with the expectation of fome future benefit, but simply because the doing itelf is the reward..." |
| HARTER 1981 | Fun experience | Joy as an affect. |
| KIMIECK & HARRIS 1996 | Fun experience | "An optimal psychological state that leads to perform an activity primarily for its own sake and is associated with positive feeling states." |
| SCALAN & LEWTHWAITE 1986 | Fun experience | "Factors such as competence and control are important in understanding enjoyment in youth sports." |
| SCALAN & SIMMONS 1992 | Fun experience | "A postive affective response to the sport experience that reflects feelings and/or perceptions such as pleasure, liking and experienced fun." |
| SCALAN ET Al. 1993 | Fun experience | Four-item indicator of sport enjoyment: enjoy, happy, fun, like. |
| WANKEL 1985 | Fun experience | Variables such as competition, curiosity, friendship and perceived social support are classified as enjoyment or quality of the experience (enjoyment as an individual perception). |
| WANKEL & SEFTON 1989 | Fun experience | "Fun is a positive affective state associated with such feelings and perceptions as happy, cheerful and friendly as opposed to sad, irritable and angry." |
| WANKEL 1993 | Fun experience | "A postive emotion, a positive affect state. It may be homeostatic in nature, resulting from satiation of biological needs, or growth oriented, involving a cognitive dimension focusing on the perception of successfully applying one's skills to meet environmental challenges." |
| DENZIN 1984 | Affect | "Temporally embodied, situated self-feelings that arise from emotional and cognitive social acts that people direct to self or have directed toward them by others. |
| CSIKSZENTMIHALYI 1990 | Pleasure | "Pleasure is a feeling of contentment that one achieves whenever information in consciousness says that expectations set by biological programs or by social conditions have been met." |
| DENZIN 1984 | Attitude | "Refers to a person's intentional value feelings toward and evaluation of some object, person, issue or event." |
| DECI & RYAN 1985 | Intrinsic motivation | "The innate, organismic needs for competence and self-determination." |

## 4.4 Quantification of fun experience in sport

In the previous sections, background on the different entities of the sport model was presented, with a focus on the interaction of an athlete with sports technology. It was noted that that the nature and analysis of motion tasks and motor learning, in addition to the engineering of technological aspects and the biomechanical context of sports technology, are fairly well supported by existing methodical approaches and validated models. However, insufficient support was identified for the evaluation of emotional aspects in connection with sports technology. It was also shown that fun related motives and resulting emotions are dominant driving forces for sports activity. Motions that result in combinations of rotation and translation of the human body seem to be a particularly important element of fun experience. The underlying quantitative kinematic variables are lateral and vertical acceleration. In almost all rolling and gliding sports and in sports requiring certain motion techniques, the generation of such acceleration is directly linked to specifications of the piece or pieces of sports technology employed. Particularly with skiing, the combination of motion technique and sports technology is central to the generation of lateral acceleration in ski turns. The goal of the present study is the development of methodical support that aims to examine and describe the effect of lateral acceleration on fun experience. This serves as a basis to verify the roles of certain motion patterns, motives and sports technology in the generation of motivation and emotions in sport. It further serves to evaluate the specific effects of a variety of sports technology in considering its contribution to the emotional experience of the athlete.

### 4.4.1 Hypotheses

Emotions are constructs and cannot be measured directly. Approaches that aim to measure constructs use a variety of quantitative and qualitative research methods that serve to circumvent this problem (Bortz, 2006, pp. 137ff). The following chapters detail the methodology that was developed for the present research. Although the model presented in chapter 4.1 is primarily technology-based, the goal of the present study relates to both areas, quantitative and qualitative research. The main hypothesis was formulated as follows.

H1: An increasing magnitude of lateral acceleration leads to a more intense fun experience.

H0: An increasing magnitude of lateral acceleration does not lead to a more intense fun experience.

The following sections present a study that was conducted to test the null hypothesis.

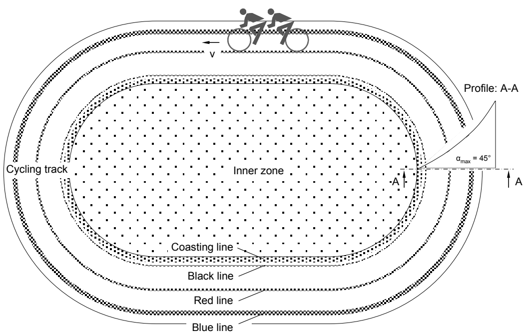
### 4.4.2 Study design, materials and methods

The study was designed as a comparative longitudinal experiment. An experimental group and a control group were tested with respect to their sensitivity and emotional response (dependent variables) to lateral acceleration (independent variable). The experimental group was subjected to a variation of the independent variable while the control group was exposed to a constant acceleration. Study of the isolated effects of the independent variable is desirable, particularly in terms of interpreting the results as they relate to more open-field experiments (see chapter 5.7). Thus, an activity with reproducible input of the independent variable (in terms of direction and amplitude) was required. Further, fun experience is a construct that depends on myriad influencing factors. Some considerations were made to satisfy the various requirements above with respect to design of a controlled scientific study:

- The lateral acceleration (independent variable) must be subject to systematic variation.
- The study setup should facilitate the isolation of lateral acceleration and its influence on fun experience (to increase internal validity).
- The motion which serves to produce lateral acceleration should be sports activity (to relate the outcomes to sports activity).
- The athletes' attention should not be entirely monopolized by the motion task. The activity should not lead to total physical exhaustion (to enable autotelic fun experience or even flow experience).
- The study should be carried out under standardized and reproducible conditions (to serve principles of reliability).
- A set of questions should be developed and presented to the athletes immediately following sports activity. They should facilitate the evaluation and quantification of acceleration perception and the quantification of fun experience.

Because of these limitations, a special test setup and environment was developed for the study. As illustrated below, visual impressions are confounding factors in the human perception of speed and contribute to the emotional experience beyond the effects of acceleration alone. They are best eliminated when athletes perform the activity blindly. Alpine skiing, which was initially considered because of its relevance with respect to future studies, is not suitable for this basic research because of the operational and systematic limitations of limiting the skier's visual input. Instead, subjects cycled blindly on the backseat of a tandem bicycle which was steered by an amateur racing cyclist. The lateral acceleration could be varied by changing the cycling velocity. Also, most of the confounding factors could be controlled to a satisfying degree with this experimental setup.

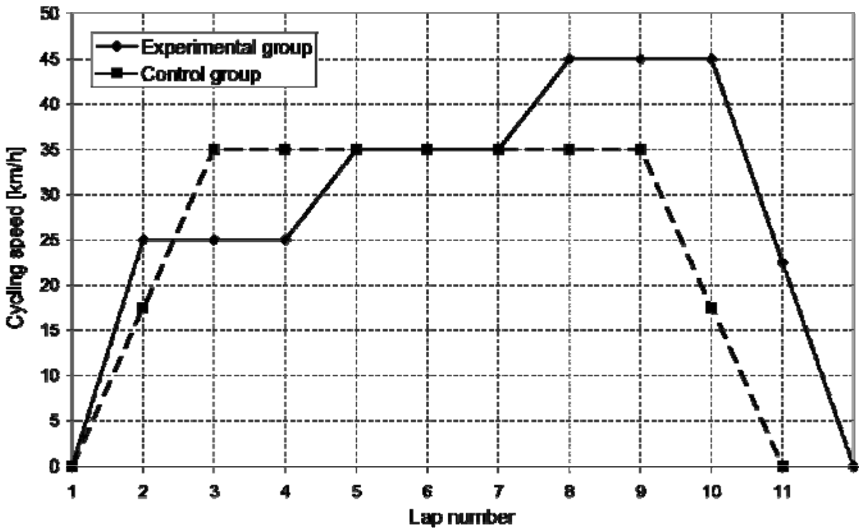
Systematic variation of lateral acceleration: As mentioned before, the independent variable should be systematically varied under reproducible conditions in the study. A velodrome provides a controlled environment for cycling with an inclined cycling track that allows different cycling velocities in the curves. The cycling track is built with increasing inclination on outer edges (Figure 4-9, left). Cycling at a higher velocity forces the cyclist to drive on a higher level of the cycling track to maintain the dynamic equilibrium of moments around the longitudinal axis (direction of motion) which are a function of the centrifugal force and the weight of the cyclist and the bicycle. The variation of the independent variable can therefore be achieved by changing cycling velocity. The mean lateral acceleration in the curves is simply a function of the cycling velocity and the curve radius. It can be estimated from geometric measures. Video analysis of the cyclists facilitated the determination of the cycling velocity and the path. Some known geometric parameters of the velodrome are listed in Figure 4-9 (right). This approach is subject to inherent limitations, including inability to cycle at a completely constant speed and uncertainties in measurement of the velodrome dimensions. As the aim of the study focuses on systematic variation of the lateral acceleration rather than an absolute determination of the cyclist's acceleration, these limitations were considered acceptable.




| *Known parameters of the velodrome* | |
|---|---|
| Location | Augsburg, Germany |
| Length black line | $l_{black}$ = 200.0 m |
| Length curve on black line | $l_{curve}$ = 62.5 m |
| Lenght straight black line | $l_{straight}$ = 37.5 m |
| Length red line | $l_{red}$ = 204.0 m |
| Length blue line | $l_{blue}$ = 215.0 m |
| Distance black & red line | $d_{br}$ = 0.7 m |
| Distance black & blue line | $d_{bb}$ = 2.3 m |

*Figure 4-9: Outline of the velodrome (left) and basic measures (right).*

The feasible magnitudes of cycling speeds were estimated in a preliminary test on the velodrome using the tandem bicycle (which was eventually used for the experiment) and the amateur racing cyclist as the driver. During the preliminary test, a bicycle computer was installed on the tandem bicycle to monitor the speed and pedaling frequency. The bicycle computer was also used in the experiment so that the driver could adjust the speed. During the study, the experimental group was subjected to three increasing cycling speeds achieved with a single acceleration lap followed by two coasting laps, repeated three times (Figure 4-10, top). The control group was subjected to constant cycling speed, introduced by two acceleration laps and two deceleration laps each. To keep the pedaling frequency constant at approximately 90 rpm, an eight-speed gear shift was installed on the tandem bicycle instead of the fixed-gear single-speed hub. The mean cycling speed and lateral acceleration obtained during the experiment were calculated from the data of all test persons (Figure 4-10 bottom).




| *Sample* | *Stage* | *Mean speed* $\bar{v}$ *[km/h]* | *Mean lat. acc.* $\bar{a}$ *[m/s²]* |
|---|---|---|---|
| Experimental group | 1 | 25.18 | 0.25 |
| | 2 | 37.62 | 0.49 |
| | 3 | 43.87 | 0.69 |
| Control group | all | 39.23 | 0.55 |

*Figure 4-10: Test cycle of the experiment and mean values of the realized cycling speed and lateral acceleration for experimental group and control group.*

Plausibility of the range of lateral acceleration with respect to skiing: With respect to the application of the present outcomes to skiing (see chapter 5), a plausibility test was conducted by comparing the lateral accelerations that could be achieved in the velodrome on a bicycle with lateral accelerations achieved in ski turns. The calculations were based on assumptions of typical skiing speeds and turn radii for average skiers (see Appendix 8.3.1). These assumptions were based on values taken from the literature (Kaps et al., 2000; Waibel et al., 2009; Mössner et al., 1997). In ski racing, however, the lateral acceleration can reach as much as 3.0 g for male downhill racers (Waibel et al., 2009). The achievable lateral acceleration is also dependent on snow conditions, ski radius, tilt of the skis and determination of the skier (Kaps et al., 2000). For the present analysis, mean values based on normal skiers were considered sufficiently representative. A comparison of the results showed that the magnitudes of lateral acceleration realized in the velodrome fit very well into the range of lateral acceleration that can be expected from normal skiers in ski turns. Figure 4-11 depicts the lateral acceleration results for a variety of typical ski turn radii and skiing speeds.

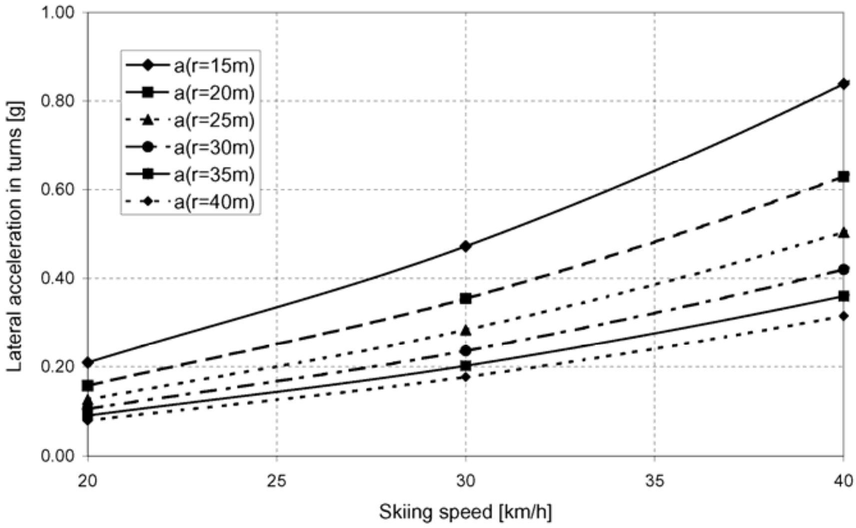



*Figure 4-11: Estimation of lateral acceleration in ski turns with respect to turn radius and skiing speed.*

Control of confounding factors: The systematic variation of the independent variable (lateral acceleration) was described in the preceding section. But to isolate the effect of the independent variable on the subjects from other influencing factors, the study design was specified as follows.

Care was taken to decouple the visual perception and lateral acceleration sensation contributions to the independent variable for two reasons. First, humans estimate speed by using visual perception and tactile receptors on the skin (including temperature perception), whereas acceleration is uniquely sensed by the vestibular organ located in the inner ear. By tracking the motion of objects relative to the body, humans are able to estimate their overall speed as well as variations in speed. Because speed is directly causing lateral acceleration in curves, it enables the anticipation of lateral acceleration. The avoid this anticipation, the sensation of speed must be eliminated as far as possible. To limit visual input, the subjects' eyes were covered with darkened ski goggles. These goggles were more comfortable than blindfolds and avoided air-stream contact with eyes and skin. Because subjects may also estimate their cycling speed by the level of exertion required during pedaling, they were also adjusted to a constant level of pedaling power during the experiment (see section below for further explanation). Secondly, visual perceptions themselves contribute to the emotional experience and fun experience during sporting activities.

The subjects were fitted with additional clothing including an integral ski helmet, ski mask, scarf, gloves and windproof jacket and trousers to reduce the sensing of cycling velocity by air-stream and air-resistance (Figure 4-12).

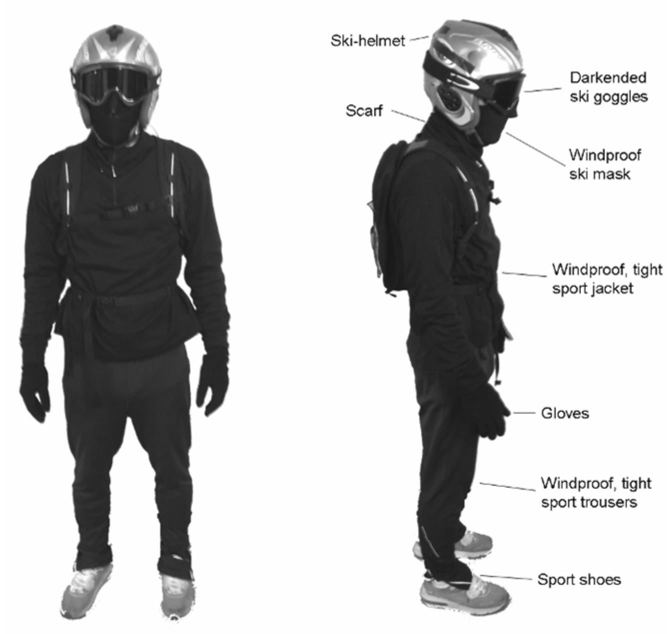



*Figure 4-12: Subjects' clothing used for the experiment.*

The demand for standardized and reproducible conditions was implicitly fulfilled by conducting the experiment in a canopied velodrome. This covered environment ensured that weather conditions did not influence the experiment and that the temperature was constant within a range of ±5 °C for the test period. In addition, the velodrome was exclusively rented for the study so that other cyclists, noise and changing light conditions did not affect the study. The track conditions were identical for all test runs.

Straight cycling is not particularly challenging in terms of motor tasks, which meets the requirement that the subjects' attention should not be entirely devoted to the motor task itself. Greater efforts were undertaken to maintain subjects' moderate level of activity during the experiment. Therefore, all subjects performed a preliminary test in which their maximum pedaling power was determined in a step test at a pedaling frequency of 90 rpm on a dynamometer. During the experiment, the subjects should not be forced to exceed 60% of this maximum level so that they are able to maintain smooth pedaling throughout experiment. This 60%-of-maximum level represents an extensive strain around the anaerobic threshold and was previously evaluated for cycling in a separate study (Mecke, 2008, p. 31ff). Further information about metabolic mechanisms in sport can be found in the literature (Heck, 1990; Stegemann, 1991; Strauss, 1983). On a tandem bicycle, both cyclists contribute pedaling power on separate cranks. This allows for a potentially uneven distribution of power between the driver and the co-driver. A power measurement crank type SRM (Schoberer Rad Messtechnik SRM GmbH) was mounted on the back bottom bracket of the tandem bicycle. The measurement crank was attached to a small terminal on the handlebar which could be monitored by the driver. The driver was then able to check the subject's actual pedaling power and adjust it to the 60% level previously established by adjusting his own pedaling power or by advising the co-driver (subject) to adjust their pedaling power with respect to the current cycling speed.

Sample group: This study aims to contribute to the understanding of fun experience in leisure sports. Thus, no semi-professional or professional athletes were included in the subject group. As mentioned above, a preliminary test was necessary to adjust the strain level in the experiment with respect to the subjects' maximum pedaling performance. The preliminary test was conducted as a step test on a dynamometer, beginning at 100 Watts and increasing the resistance every three minutes by an additional 50 Watts. The subjects' position on the dynamometer was standardized. The test was terminated as soon as the pedaling frequency fell below 90rpm because of the subject's fatigue. In addition, all subjects completed a modified activity questionnaire. Based on the results of the questionnaire, an activity index A is assigned to each subject (Oberger et al., 2006, pp. 44ff). A Kendall Tau-b test showed a positive correlation between the results of the preliminary test and the activity index. This suggests that a higher activity index corresponded to a higher maximum pedaling power. Generally, the subjects were moderately active – a result which can be taken as a typical activity level in leisure sports. Several additional characteristics of the sample group are summarized in Table 4-4. The sample group was randomly divided into two groups of 12 persons each: the experimental group (which was subject to the treatment in the experiment) and the control group.

*Table 4-4: Characteristics of the sample group*

| *Sample group parameter* | *Specification* |
|---|---|
| Size | N = 27 |
| Participants | n = 24 (2 injuries, 1 failing check-up) |
| Age | $\bar{x}$ = 24.0 y (SD = 3.1) |
| Gender | male |
| Max. pedalling frequency | **P** = 258.3 W (SD = 56.5) |
| Activity index | **A** = 1.71 (SD = 0.86) |
| Activity level | medium active |
| Correlation P and A | r = .33 (α = 0.05, p = 0.035) |

Development of the questionnaire: As discussed previously, no valid methodical alternatives are available to support the evaluation of fun experience in connection with motion or to evaluate the specific interaction mechanisms between lateral acceleration and the resulting fun experience. Therefore, a new questionnaire was developed to test the study hypotheses. The questionnaire consisted of three categories, as listed below, and a section to the evaluate of perceived side effects of the experimental setup.

1. Questions about the physical sensation of lateral acceleration and the emotional sensations regarding fun experience during the test cycle.
2. Questions about the experience with tandem bicycles, experiences and impressions in exercising blindly, the confidence in the driver and possible anxieties during the test cycle.
3. Questions about sport habits and sport motives.

Question category one is the main focus of the questionnaire. The specific questions in this portion of the questionnaire were created from various sources: studies and publications (see state of the art: fun), a brainstorming session (with staff from the Department of Sport Psychology, Technische Universität München; questions were created by means of abstraction and analogy) and from impressions noted during the pilot test (which was conducted before the study to verify the experimental setup).

Literature findings regarding fun experience in sports activity served as the basis for development of questions regarding the general emotional state, for example, "I feel: absorbed, active, energized, good physically, exhilarated, stimulated or a sense of accomplish."

In addition, it was important to develop specific questions regarding the perception of acceleration. Forming analogies proved to be an acceptable method of developing questions for this portion of the questionnaire. For example, imagine how it feels while riding an elevator or a roller coaster, free-falling, landing an airplane or sitting on a carousel.

Further, the feeling of acceleration was transcribed, for example, as getting dragged from the bicycle, clasping to the handlebar to prevent being pulled off or getting squeezed into the curve.

For all questions, a number of sub-questions were formulated. These sub-questions were used to evaluate whether the sensations described above were joyful (fun experience), if the sensations increased or decreased during the experiment and in which phase the sensation was most intense. Straightforward questions were used to evaluate fun experience and lateral acceleration and addressed topics such as driving into the acceleration, the sensation of fun experience, which phase was more fun experience, were the straight lines or the curves more fun experience, did the acceleration increase/decrease.

The complete set of questions can be found in the questionnaire (see Appendix 8.3.2). Questions in category two were created exclusively from experiences noted during the pilot test. The questions about sport habits and sport motives were created using literature sources and the results from the surveys presented in chapter 3. The rating scale for the closed questions was a four-step ordinal scale (“fully applies” = 4 to “does not apply” = 1). An even number of response categories without a neutral category was chosen to avoid the general tendency towards neutral responses, the so-called acquiescence, in surveys (Bühner, 2006, p. 63). The following list presents examples for each question category.

1. – Did you have a prickling feeling in your stomach during the test cycle?
   – Did you have the feeling of getting pushed into the turns?
   – Did you enjoy the curves more than the straight parts of the track?
2. – Did you feel uncomfortable when cycling blind?
   – Was it a new motion feeling for you when cycling on the tandem bicycle?
   – Did you feel that the driver had everything under control?
3. – I exercise because I enjoy motion.
   – I exercise because I want to increase my physical performance.
   – I exercise because I want to get in touch with other people doing sport.

More than two sub-questions were formulated for each question to increase the validity of the outcomes. The questionnaire was presented to five interviewees before the experiment to establish the comprehensibility, but no further evaluations were conducted to test the reliability and the validity of the questionnaire.

### 4.4.3 Execution of the experiment

Before the experiment, a pilot test was conducted to check the hardware equipment (e.g. control of cycling power, gears for constant cycling speeds), verify the general experimental setup and familiarize the designated driver with the tandem bicycle (also: ensure adequate communication with the co-driver was possible). Further, initial impressions about emotional experiences and sensations during cycling as the co-driver were collected and used in the creation of the questionnaire.

The results from the pilot study showed that the blind co-driver setup was less of an inconvenience than was expected. The co-drivers in the pilot test cycled more smoothly and with less disturbing body shifts when cycling blind. Positive emotions and even euphoria were experienced by the test drivers. Furthermore, the sensitivity for vestibular perception of acceleration reportedly increased when cycling blind because of the absence of other sense organs. The experiment was conducted between December 10th and December 13th, 2007, according to the following test plan:

1. Transfer the subjects and provide detailed briefing and instruction in a separate room. Subjects do not view the velodrome itself, neither are they introduced to the experiment’s purpose.

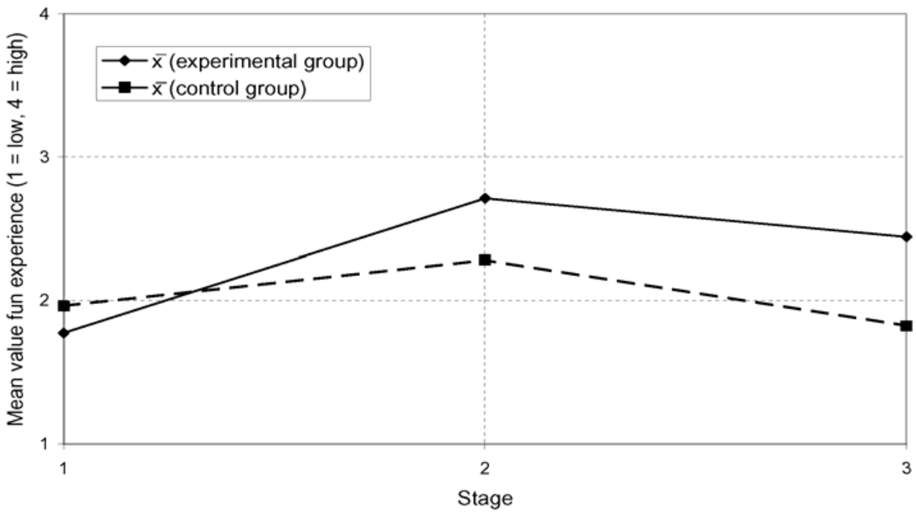
2. Equip the subjects with special clothing and accessories and guide them to the velodrome (already blindfolded). Adjust saddle position.
3. Inform the driver about the pedaling power limit and begin warm-up laps. Make sure that the subject is comfortable. Start of the test cycle.
4. Guide the subject back into the separate room (still blind), isolate him from the other subjects, and take off equipment.
5. Hand out the questionnaire to the subject immediately after the experiment and inform them about the purpose of the experiment.

Figure 4-13 shows two video screenshots at the slowest and fastest cycling speeds.

*Figure 4-13: Video screenshots at slowest cycling speed (left) and fastest cycling speed (right).*

### 4.4.4 Results

Lateral acceleration and fun experience: Questions relating to lateral acceleration and fun experience were amassed to test the main hypothesis (see questionnaire in Appendix 8.3.2). The descriptive statistics show a similar fun experience during the experiment for both the experimental and the control group (Figure 4-14). In the figure, a larger value on the y-axis corresponds to a more intense sensation of fun experience. The maximum sensation of fun experience was observed during stage two of the experiment. During the test cycle, the lateral acceleration was greater during stages two and three compared to stage one for the experimental group, while it remained at an constant level for the control group (see section Systematic variation of lateral acceleration above). The data indicates that the difference in the sensation of fun experience between stage one and stage two was greater for the experimental group ($\Delta = 0.94$) than for the control group ($\Delta = 0.32$). The decrease in the sensation of fun experience from stage two to stage three was less prominent for the experimental group ($\Delta = 0.27$) than for the control group ($\Delta = 0.46$).




| Test cycle | Experimental group (n=12) | | Control group (n=12) | |
|---|---|---|---|---|
| | x | SD | x | SD |
| Stage 1 | 1.77 | 0.40 | 1.96 | 0.51 |
| Stage 2 | 2.71 | 0.59 | 2.28 | 0.73 |
| Stage 3 | 2.44 | 0.54 | 1.82 | 0.54 |

Note: 1 = low fun experience, 4 = high fun experience

*Figure 4-14: Descriptive statistics for the subjects' sensation of fun experience during the test cycle.*

Using an inferential statistical analysis, the differences in fun sensation were tested regarding their significance with respect to the main hypothesis. With a significance level $\alpha = 0.05$, paired comparisons revealed that the means of fun sensation in stages two and three ($p_{stage2} = 0.002$, $p_{stage3} = 0.010$) differed significantly from mean values in stage one in the experimental group (see mean deviation in Table 4-5, top). Furthermore, the test on intra-subject effects (comparison of fun sensation within each subject) and the test on inter-subject effects (comparison of fun sensation between subjects) was significant ($p_{intra} = 0.001$ and $p_{inter} = 0.000$) with a very high effect size (power) of 0.95.

For the control group, the mean values between the stages did not vary significantly ($p = 0.120$). The paired comparison showed no significant effects in the sensation of fun experience between the different stages and the intra-subject effects were not significant ($p_{intra}$ = 0.108). In contrast, the inter-subject effects were significant ($p_{inter}$ = 0.000) with an effect size (power) of 0.407.

The decrease in fun sensation from stage two to stage three was not significant in either subject group (Table 4-5).

*Table 4-5: Statistics of the paired comparison of fun experience between the stages for experimental group and control group, respectively*

| *Paired comparison* | | *Statistics experimental group* | | | *95% conf. interval for deviation I-J (a)* | |
|---|---|---|---|---|---|---|
| Factor 1 (I) | Factor 2 (J) | Mean deviation (I-J) | Standard error | Significance (a) | Upper limit | Lower limit |
| Stage 1 | Stage 2 | .934 (*) | .194 | .002 | .388 | 1.480 |
| Stage 1 | Stage 3 | .666 (*) | .178 | .010 | .163 | 1.168 |
| Stage 2 | Stage 3 | -.269 | .149 | .296 | -.688 | .151 |

Based on the estimated rand index
(*) The mean deviation is significant on the .05 niveau
(a) Matching for multiple comparison: Bonrerroni

| *Paired comparison* | | *Statistics control group* | | | *95% conf. interval for deviation I-J (a)* | |
|---|---|---|---|---|---|---|
| Factor 1 (I) | Factor 2 (J) | Mean deviation (I-J) | Standard error | Significance (a) | Upper limit | Lower limit |
| Stage 1 | Stage 2 | .317 | .187 | .355 | -.211 | .845 |
| Stage 1 | Stage 3 | -.140 | .229 | 1.000 | -.786 | .506 |
| Stage 2 | Stage 3 | -.457 | .209 | .154 | -1.047 | .133 |

Based on the estimated rand index
(a) Matching for multiple comparison: Bonrerroni

Finally, the overall effect size (power) of the questionnaire regarding the variable of interest (sensation of fun experience) was 0.971, indicating a high probability of finding the actual effect with the given data set.

Influence of confounding factors: The activity level of the subjects can be considered a confounding factor. A higher general activity level of athletes, for instance, may lead to an increased sensation of fun experience in situations of lateral acceleration or vice versa. Therefore, a test was conducted to determine if the activity index has an influence on the sensation of fun in regards to the experimental setup. The subjects were divided into two groups of six subjects in terms of the mean activity index that was determined during the preliminary test: one group comprised of the less active subjects and the other group with the more active subjects.

Considerable differences were observed in the descriptive statistics for the sensation of fun between the less active subjects and the more active subjects in both the experimental group and the control group (Figure 4-15). However, none of these effects were identified as being significantly different using the paired comparison test, the test on intra-subject effects or the test on inter-subject-effects in either the experimental or control groups. This means that the general activity level of the subjects does not have a significant influence on their sensation of fun experience during the test cycle in the present study.

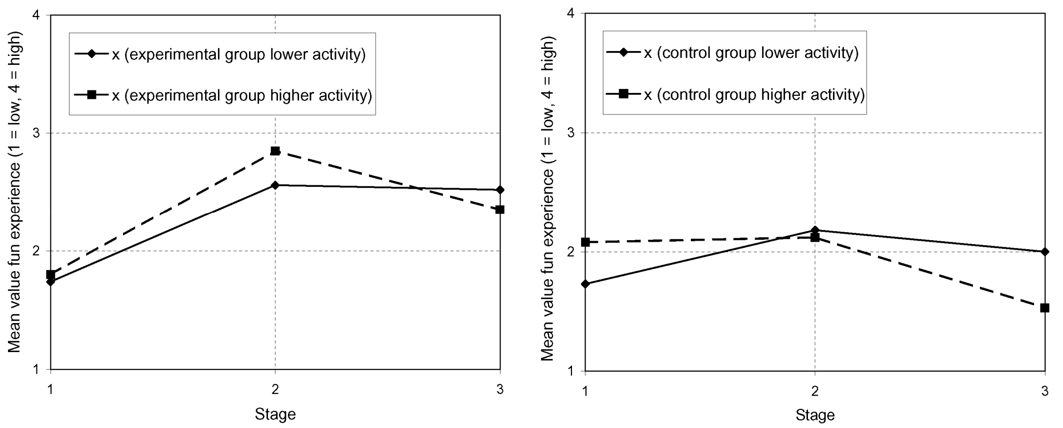



*Figure 4-15: Descriptive statistics for the influence of the activity level of the subjects on the sensation of fun experience. The standard deviation is not depicted because of clearness.*

Other possible confounding factors include distractions noted by the subjects: driving blindly, cycling on a tandem bicycle for the first time, not having confidence in the driver or feeling uncomfortable in the special clothing. The questionnaire was designed to address these issues and gauge how the subjects responded to the different factors. Table 4-6 depicts the results concerning the potential distractions. The subjects deemed being blinded as moderately distracting while the driver and the clothes did not appear to influence the subjects. Cycling on a tandem bicycle was a new experience for most subjects.

Another interesting effect was noted during the pilot test on the velodrome prior to the execution of the experiment. Because of the lack of sight, other sensations seemed to intensify during the test runs. This sensation was also evaluated through the questionnaire. Almost all subjects reported having some of their sensations intensified during the test cycle, especially the auditory and vestibular senses (see Table 4-6).

*Table 4-6: Influence of distracting factors and intensification of sensations during the test cycle*

| *Effects* | *Statistics (n = 24)* | |
|---|---|---|
| *Distractions* | *1 Rating scale 4* | *1 = low, 4 = high* |
| Blindness | | $\bar{x}$ = 2.85 (SD = 1.08) |
| Novelty of tandem experience | | $\bar{x}$ = 2.96 (SD = 0.99) |
| Driver or clothes | | $\bar{x}$ = 1.75 (SD = 1.01) |
| *Sensations* | | *Distribution yes/no* |
| Intensification of sensations | | 91.7 % / 8.3 % |
| Type of sensation that intesified | Hearing sense<br>Sense of acceleration<br>Sense of balance<br>Sense of inclination in space | |

### 4.4.5 Discussion

Fun experience: By examining the subjects' reported sensation of fun experience, it was determined that the subjects in the experimental group experienced significantly more fun because of the increase in the lateral acceleration in turns relative to the control group who experienced a constant level of acceleration. Additionally, the fun experience reported by the experimental group increased significantly with higher lateral accelerations. The results showed that acceleration in general was related to a higher level of fun experience.

H0 is rejected, H1 is confirmed: An increasing magnitude of lateral acceleration leads to a more intense fun experience.

The confirmation of the main hypothesis is only valid within the range of lateral acceleration that was produced by this experimental setup. The reported level of sensation, however, did not increase between stage two and stage three of the test cycle. This lack of change in sensation may originate in the fact that the subjects likely could not distinguish stage three from stage two as clearly as they could distinguish stage two from stage one. According to the test setup, the first stage was conducted on the lowest level of the velodrome where the acceleration consisted of gravity normal to the driving direction and acceleration acts radial in the curves. In contrast, stage two and stage three were conducted on the banked part of the velodrome. In these cases, gravity in the curves not only acts on the cyclists in the normal direction, but also has a component resulting from the centrifugal force. This contributes to the lateral acceleration sensation and leads to a more intense feeling of overall acceleration. Therefore, the difference from stage two to stage three, which were both driven in the banked part of the velodrome, may not be as striking as the difference between stage one to stage two. Furthermore, a slight effect of familiarization might have taken place by the time stage three was reached. That is, the increasing expectations of the subject were not met by the activity. It is also possible that the acceleration in stage three was already at a maximal level for some of the subjects. The difference in fun experience between stages two and three was not significant, though. In this sense, the fun experience on stages two and three may be regarded as functionally equivalent.

In the control group, it was observed that despite the nearly constant level of cycling speed and lateral acceleration, the sensation of fun experience was rated differently for the three phases of the test cycle (similar to the stages in the experimental group, these were: beginning stage, middle stage and final stage). However, the maximum difference between mean values of any two stages was only 8.7%. Because none of these deviations were significant for the control group, no statistical effect is evident and the fun experience is considered nearly equivalent for all three phases of the test cycle.

Finally, the mean fun experience of the third stage of the experimental group ($\bar{x}$ = 2.54) was considerably higher than the mean of the control group ($\bar{x}$ = 2.02). As discussed above, the constant phase of the control group was equivalent to stage two of the experimental group. This may represent an objective basis for comparison and might help to explain the slightly lower ratings of the experimental group for stage three compared with stage two, as the stage three rating is still greater than the ratings of the control group.

Confounding factors: It was shown that the subjects' activity index did not have a significant influence on the sensation of fun experience in either the experimental or the control group. This means that the subjective sensation of fun experience is not affected by the physical fitness during the test cycle. Furthermore, the results indicate that the study was likely insensitive to any potential biases in activity index of the recruited subjects. This is particularly important because study subjects were male student volunteers rather than a random sample from a large leisure sports population. Some differences, however, can be observed in the statistics (Figure 4-15). The results from the more active subjects vary considerably compared to the results from the less active subjects. This might originate from the fact that the more active subjects were more comfortable with the setup than the less active subjects, and therefore experienced a more joyful test cycle from the beginning while a certain familiarization caused their joyful experience wear off more quickly. The less active subjects might have felt less comfortable with the situation such that they required a certain period to acclimate to the situation.

The distraction by blindness had a mean rating of 2.85, which suggests that the subjects were considerably distracted by this setup. Because none of the subjects had exercised sport blindly before, the setup was a completely new experience for them. Fun experience is lessened instead of accentuated by the blindness, and therefore does not negatively affect the outcomes of the study concerning the main hypothesis. The general sensitization because of blindness during the test cycle, especially the intensification of the vestibular sense, can be seen as an indicator that the subjects were able to feel the lateral acceleration even more intensely than they would have with open eyes. In this sense, blindness can be considered a synergist for the reported fun experience. Most of the subjects stated that cycling on a tandem bicycle was a novel experience for them ($\bar{x}$ = 2.96). However, they did not report feeling distracted by the fact that they were riding on the backseat under conduction of a formerly unknown driver or by the unfamiliar clothing they were wearing ($\bar{x}$ = 1.75). Nor did the subjects state that these impression deteriorated during the test cycle. In fact, these findings give reason to the assumption that the new cycling experience did not lead to a negative impression or to corruptive emotions with respect to fun experience.

None of the confounding factors were found to produce corruptive or biasing tendencies with respect to the sensation of fun experience in this experiment. This suggests that the significance of the effects found in the experiment were not affected by confounding factors that might have influenced the outcome variables.

## 4.5 Summary

The present chapter has been devoted to the comprehension of the role and the quantification of the effect of fun experience in leisure sports. Experimental investigations were conducted for cycling, and the results were extended for application to skiing. There were two major accomplishments of the study.

First, a prescriptive model was presented that describes the athlete in a sports activity. It enables the understanding of the roles of sports technology in a complex environment and opens the field to a novel approach on sports technology design that aims at the creation of enjoyable sensations. Two entities of sport were defined: the sport context and the sports activity. The sport context describes the individual sport motives of an athlete, the motion tasks (which are the motions that will be performed in a sport, rules that have to be followed, etc.), and the required sports technology that form the necessary environment for exercising sport. While the motivational background of an athlete is relatively stable, the motion task changes with the sport and the level of aspiration. Sports technology represents a physical link to the athlete, an extension of the human body. It can be adjusted to enhance sports activity with respect to a given set of individual prerequisites (which are defined in the sports activity) by taking into account the motion task and individual motives. For instance, each athlete aims to satisfy his individual motivation with respect to his own level of physical strength and motor skills.

Second, the link between the emotional state of an athlete and a piece of sports technology was evaluated. The goal was to test systematically if lateral acceleration had a positive effect on fun experience. To accomplish this, a questionnaire was developed with the purpose of evaluating fun experience. The questionnaire was based on literature research and the development of new questions to address the specific test conditions. The study also included selection of an experimental and a control group, and having the subjects' cycle blindly on the backseat of a tandem bicycle in a velodrome. The velodrome facilitated the systematic variation of lateral acceleration, but only the experimental group was subjected to variation. The range of lateral acceleration achieved in the velodrome was shown to correspond to the range that can be achieved in ski turns in leisure skiing.

The results for the experimental group showed that a higher level of lateral acceleration leads to a more intense sensation of fun experience and enjoyment. Generally, the lateral acceleration caused a high level of fun experience. The results were not sensitive to the confounding factors discussed above.

Therefore, the questionnaire was shown to provide a valid basis for the quantification of fun experience in similar settings of lateral acceleration and can thus serve in the validation effects of sports technology on the emotional state of the user.

# 5 Application of the sport model: Design of a training feedback system for skiing


In the present chapter, the sport motivation model and its effects on the understanding of emotional experiences and motor learning as well as their interaction with product functionality are extended to an example design application. The example is presented to verify practical applicability of the previous findings. Chapter 3 has shown that technical innovations in alpine skiing stall recent years and proclaimed improvements often turn out to be exaggerations of a strongly market driven industry. Product differentiation is often merely a difference in outer appearances. This lack of technical innovation has become increasingly recognized by the users. As soon as saturation or even a shrinking market is evident, continuity and expansion can only be achieved through innovation or crowding out by means of selling under value. “The skiers”, states one retailer, “have alienated from their skis mainly because they no longer see any benefit in annually buying literally the same ski”. The example presented in this chapter describes the realization of mechatronic sports technology. It refers to the design of a technique-based feedback system for alpine skiing, verifies whether or not audio feedback training is a proper method in improving skiing technique and examines if fun experience in skiing can be intensified by improving skiing technique. The project was supported by the work of various students under the supervision of the author of this thesis including Wolfgang Bauer, Axel Czabke (Czabke, 2007; Czabke, 2008), Andreas Lipp (Lipp, 2009), Tobias Maletz (Maletz, 2007), Simon Vogt (Vogt, 2008), Patrick Werner (Werner, 2009) and Florian Zierer (Zierer, 2008).

## 5.1 Concerning instances of the sport model

In product design, the awareness of certain problems and specific tasks during development often helps in the selection of an appropriate development method from the numerous method options available in different scientific disciplines. For the present design, the previously presented sport model helped clarify a variety of aspects that needed to be considered in the design focus. A brief overview of these design considerations is provided below with an emphasis on integrating the findings of the preceding chapters (see Figure 5-1).

Initially, the characteristics of the instances of the sport context entity and their interaction mechanisms with the athlete were clarified. Skiers' sport motives were evaluated before the design efforts began. It was assumed that skiing is considered predominantly a fun sport when exercised leisurely, but the coherence between skiing technique and the sensation of enjoyment has not previously been examined. This statement was verified with respect to the sports activity entity in the evaluation study (see motivations and emotions as well as motor skills in Figure 5-1). Before the actual design of the training feedback system (sports technology in Figure 5-1) could begin, the theoretical background of the motion tasks in skiing and the interaction mechanisms of motor learning and feedback with the athlete were reviewed. In addition, fundamental research had to be conducted to verify whether the basic method for feedback generation was feasible for the design objective. In the present example, it was useful to begin the clarification phase on the sport context entity with a clear concept of the design tasks. The sports activity entity was used next to evaluate the functionality of the training feedback system. The physical strength instance was not considered in the design because the main objective was to improve motor skills and enhance emotional sensations. In other contexts, however, it may also be feasible to initiate research in testing the emotions of athletes with respect to physical strength (e.g. when optimization of a piece of sports technology is required regarding the biomechanical interface, usability or performance).

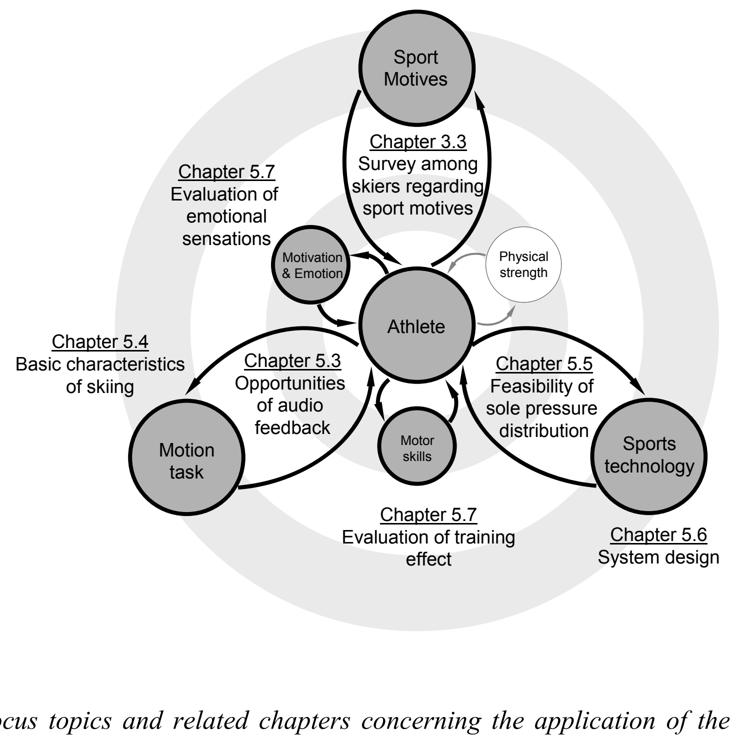



*Figure 5-1: Focus topics and related chapters concerning the application of the sport model to the design of a training feedback system for skiing.*

In addition, the results of the surveys presented in chapter 3 contributed to the system design and evaluation. The most important aspects identified include the following:

- Demographic shift: Because of the demographic shift, the average age of people engaged in sports activity is increasing. This is an opportunity to introduce a training feedback system because aspects such as avoiding overstrain or increasing safety in terms of improved motor skills has become more important.
- Trend towards outdoor sports: There has been a trend towards outdoor sports in recent years. In most outdoor sports, athletes rely on self-education for training and motor skill development. Training feedback systems can support and enhance this education processes.
- Limited time frame of the working society: The decreasing participation in sport for people aged 30 and older is likely the result of limited time frame between work and family life. Additionally, many people likely do not actively participate in a sport that they previously participated in because of a sense of anxiety about failing. A training system that helps facilitate reintroduction to a sport by accelerating motor learning or refreshing previously acquired motor skills would likely appeal to a large market of people from the middle or upper classes.
- Fun orientation in leisure sports: The general concept of introducing fun into leisure sports opens the field for new applications utilizing mechatronics. Playing with motion, direct feedback and monitoring improvements can be a source of enjoyment themselves.
- Few products on the market: To date, there is a generally low rate of product implementations in the segment of mechatronic sports technology; in particular, there is an absence of real-time training feedback devices which aim to improve motor skills. This deficiency in the market provides a unique opportunity for the initial developers of such designs.
- Important requirements: Some important prerequisites required in the design of mechatronic sports technology were identified from the surveys presented in chapter 3: perfect usability, easy to handle, low power design, reasonable prices, resistant to environmental impacts and a clear training benefit. Attention to these details needs to be an important part in the development. Recent product examples on the market, both successful and unsuccessful, suggest that market success is directly related to the fulfilment of these prerequisites.

Once a general orientation is accomplished, such as, for instance, navigating through the sport model, the specific design and evaluation methods have to be selected situation-specific. In the subsequent sections, the prior investigations and research as well as the system design and its evaluation are presented in detail.

## 5.2 Background and idea behind the Digital Skiing Coach

Since its origin in the mid 19th century, skiing has epitomized the "competition versus leisure" dialectic of sport. Walking on snow with long laths, especially when people were carrying loads, had been used as a functional approach to avoid sinking into the snow; however, the idea of gliding downhill was invented by young Norwegian men who performed jumps with their laths "just for the fun of it". Since then, the focus of skiing as a leisure sport has included the enjoyment of motion, experience of free nature and social aspects. More than ever, the emergence of carving skis facilitated the mastering of ski turns and the experience of acceleration through increased turning speed. A solid basis in skiing technique, however, is still necessary to achieve proper carving technique.

Alpine skiing is a very challenging sport to learn because of the numerous degrees of freedom in movement and the many different motion situations. Therefore, the level of enjoyment experienced during skiing greatly depends on an individual's motor skills. Taking into account the eight basic characteristics of good skiers as established in current skiing curriculum, the beginner skier faces an abundant number of challenges related to a complex motion sequence (Reinboth, 2006). Hence, professional instruction is usually necessary. Based on the fundamental characteristics of skiing, a major problem becomes obvious with observation of beginning skiers. Most skiers who have acquired a minimal amount of skiing experience are incapable of adjusting and controlling body position above the skis in turns (Scheiber, 2004). This is the fundamental concept behind the presented research.

The idea behind the presented design was to enhance the learning process in skiing by means of a "Digital Skiing Coach" that provides real-time feedback about basic motion parameters. The term "coach" refers to fact that the system needs to be able to provide valuable advice for athletes. The advice should be based on the measurement of ski load distribution during skiing and an underlying expert interpretation system (Figure 5-2). Thus, the learning process could be facilitated through a direct "sense" of motion, and produce and intensify enjoyment by playing with the body or by mastering more challenging skiing situations.

*Figure 5-2: Concept of the Digital Skiing Coach: measurement of sole pressure distribution, data analysis and interpretation results in real-time audio feedback.*

Such endeavors at motion analysis, interpretation and reproduction of information have not been attempted before and required profound investigations in terms of both sports science and technological development. The main elements of these efforts were the quantitative analysis of skiing technique and the the functional realization of a mechatronic system.

The results from chapter 3 emphasize that the potential use of mechatronic systems in sport can be considerable but are subject to a variety of prerequisites that need to be met to achieve consumer acceptance and market success. The German inter-trade organization for information technology (BITKOM) stated in its survey sensor based sports technology as a growth market if major technological and methodical problems can be solved. Thereafter, market volume may increase until the year 2015 from approximately 100 Mio. € per year to 4.3 Bio. € per year in the best case and at least up to 650 Mio. € per year if some of the preconditions cannot be satisfied (Hintemann, 2007, p. 21). Mechatronics appears to be a good opportunity to generate the basis for sustainable innovations in sports technology.

Apart from various existing applications in performance sports, mechatronic systems in the leisure sports market currently provide only limited motion or vital parameters. A popular example of a mechatronic system used in leisure sports is heart rate sensors, which generate real-time information about the heart rate during sports activity for the purpose of training control. In addition to the visual display of information, most of these systems also produce a simple audio feedback, “beeps”, to indicate upper or lower heart rate limits. The Nike+ Sport Kit (Figure 5-4) is the only system currently on the market that utilizes a similar technology to the work presented here. The technology used in the Nike+ Sport Kit includes a step sensor which can be incorporated into running shoes and used to measure running speed, the number of steps and is even capable of adjusting the volume of music played on an Apple iPod to the rhythm of running. In addition, a web platform can be used to store and compare training data. The Nike+ Sport Kit is a well designed system and can serve as a benchmark in terms of mechatronic product usability. However, the device is not suitable to provide feedback about running technique or more complex motion patterns.

*Figure 5-3: Concept of the Nike+ Sport Kit with integrated coin-like step sensor in a running-shoe (source: Nike Inc.).*

With respect to its market relevance, the research and design efforts of the present project are directed at answering a number of questions about motion and technological character as related to the “sport model” developed in chapter 4.1. The following research questions affect the sports activity entity of the sport model in terms of emotional effects and learning mechanisms:

1. Is the Digital Skiing Coach a suitable system to enhance fun experience in skiing?
2. Is it possible to enhance skiing technique using the Digital Skiing Coach?

To create a basis for addressing these topics, several research questions must first be addressed. These preliminary questions are located in the sport context instance of the sport model and deal with the different aspects of functionality. Despite their mainly methodical and technological character, the design decisions for these aspects were posed as questions because a positive outcome was initially questionable.

3. What is appropriate feedback for technique-based feedback in skiing?
4. What are the basic characteristics of skiing technique?
5. Can basic characteristics of skiing technique be operationalized in a way such that motion patterns can be displayed by a sole pressure measurement system for leisure skiing?
6. Is it possible to design a mechatronic system which is easy to handle and capable of producing the necessary data in real-time?
7. Is it possible to develop and implement an algorithm which is capable of analyzing, interpreting and reproducing the provided data in real-time?

In the following chapters, the approaches chosen to answer these questions and the main results will be described.

## 5.3 Motor learning and feedback in skiing

The first step necessary in the development of a technique-based feedback system for skiing is to establish an understanding of the process of motor learning, specifically with respect to skiing. In addition to the learning process itself, it is important to understand which mechanisms can be used for training feedback. The background information obtained contributed in answering research question three:

3. What is appropriate feedback for a technique-based feedback system in skiing?

The following citation illustrates the crucial importance of motor learning with respect to leisure sports:

“Any kind of sports activity includes the education of sport-related motor skills and motor abilities, independently from corresponding aims and goals. This applies not only with respect to performance sports, but in the same way also for enabling sports activity at all – leisurely or not” (Schnabel et al., 2006, pp. 146ff).

### 5.3.1 The process of motor learning

As we see from the citation above, motor skills and motor abilities are the essential elements of motor learning. With respect to a training feedback system, it is important to understand the difference between these elements. Motor ability is defined as the individual sport competence of an athlete. It is characterized by the level and quality of psychophysical operations. In other words, motor abilities are prerequisites which principally allow an athlete to accomplish a specific sports activity (Schnabel & Thiess, 1993, p. 283). Motor abilities can be subdivided into conditional (physical) and coordinative (informational) processes. Motor skills are the fundamentals of an activity that go on automatized. These skills are initially regulated consciously and can be transformed to motor automatisms (engrams) on the basis of motor abilities (Schnabel & Thiess, 1993, p. 155). Simplified, motor abilities produce the basis for the adoption of motor skills. In skiing, the adoption of motor skills is essential in mastering different environmental conditions. Thus, the aim of a training feedback system is the activation of motor abilities to enhance motor skills.

Because the transition from motor abilities to motor skills requires complex information operations and memorization, the learning process itself is usually characterized by the basic sub-processes of reception, information processing, assessment, framing, memorization and completion and control mechanisms. The motor learning process is therefore an iterative process with the intention of matching the motion task with the individual skills (Schnabel & Thiess, 1993, p. 547). Apart from the motor abilities, the sensory, cognitive and emotional abilities are of significant importance for learning processes (Scheid & Prohl, 2007, p. 51). Motor learning depends on the successful balancing and interaction of these aspects. This is one reason why the understanding of the athlete's motivational and emotional contexts is essential for enhancing motor learning. We will see in the evaluation study that motivation and emotional aspects are important design considerations that affect the efficacy of the Digital Skiing Coach and sports technology in general.

Until now we have focused on the functional aspects of learning processes. But the term "process" implies that these mechanisms are not instantaneous but rather develop over a period of time during which the quality of motor ability and motor skills improve. Thus, motor learning is a sequence of achievable objectives (Rieder & Lehnertz, 1991). The didactic-methodical fundamentals of the process of motor learning must be clear as we aim for the design of a training feedback system. The feedback system must incorporate concepts which allow for the adjustment of training support to the actual skill level of the athlete. The learning process is typically explained by three consecutive phases that were originally defined by Meinel (1960).

Phase one, "learning":

In the first phase, the athlete acquires knowledge about the basic principles of motor skills and applies these skills in motion activity. The achievement of these motion activities, however, is still characterized by a lack of consistency and economy in efforts. The deficiencies lay in an inappropriate perception and operation of information. The motion activity is mainly completed by visual feedback from the visual exteroceptor.

Phase two, “adopting”:

In phase two, the motion tasks are completed properly in an environment without disturbing influences. But unfamiliar environmental conditions or varying motion tasks can be distractions that hinder the quality of the motion sequences. The focus in this phase is the development of the information perception and operation in terms of the proprioceptors. In particular, the kinaesthetic analyzers (muscle control) become more important (Schnabel, 2007, p. 184). In addition, the perception of secondary information in terms of auditory advice and feedback (from instructors or trainers) plays an important role in correcting motor deficiencies. Because the allocation of appropriate information about motion technique is a core aspect of the Digital Skiing Coach, we will have a closer look at the different forms of information perception and feedback below.

Phase three, “perfecting”:

Perfecting comprises the development of fine motor skills up to a level where the motion task can be completed even under unfamiliar and challenging conditions. Motions become more automated and the athlete can concentrate on increasing his physical performance. Certain aspects of the motion task, though, are given conscious thought and attention for further fine-tuning. The information perception is further enhanced by emphasizing the proprioceptors (Birklbauer, 2006, p. 341). Nevertheless, the athlete requires further information for self-perception and auto-correction. Extrinsic acoustic feedback (chapter 5.3) is of specific relevance here.

In Table 5-1, the three phases are depicted in connection with typical contents of the skiing curriculum to clarify the application of the theoretical background presented above in the context of a training feedback system for skiing. The design of the training algorithms for the system was largely based on these three phases.

A variety of learning models were established to explain the chronology of learning processes. Two main concepts can be distinguished that are not entirely independent and entail varying consequences for the practice of teaching and training: the motor approach and the action approach (Birklbauer, 2006, pp. 497ff). The motor approach is based on the theory of information operation processes which were developed in psychology to explain human behavior. The action approach originates in the theory of system dynamics and incorporates concepts of self-organization of motor activity. With respect to current skiing curricula, both concepts are important for the Digital Skiing Coach and bear further discussion. The motor approach is characterized by simple guidelines for the stepwise increase of the motion challenge, progressing from the known to the unknown and from generalized principles to individual differentiation.

*Table 5-1: Phases of the motor learning process (left), core characteristics of the main phases and their application in skiing (according to Birklbauer, 2006; Schnabel, 2007; Wörndle et al., 2007, pp. 47ff). The focuses of the training feedback system presented in this thesis are highlighted grey*

| *Learning phases* | *Characteristics* | *Application in skiing and focus of the present reseach* |
|---|---|---|
| Phase 1: Learning<br>*Development of basic coordination* | - Excessive effort of muscle power<br>- Insufficient information perception and operation<br>- Inappropriate anticipation of motional tasks | - Gliding (balancing the body)<br>- Plow (stopping)<br>- **Turns (carving, skidding, regulation of speed and stopping, body position)** |
| Phase 2: Adopting<br>*Development of fine motoric coordination* | - Optimization of efforts of muscle power<br>- Context related adoption of effort and rhythm<br>- Specification of anticipation of motional tasks<br>- Insufficient constancy in unfamiliar situations | - **Parallel skiing (chipping edges, turning, steering)**<br>- Carving (dynamic change of direction, anticipation of situations, safety) |
| Phase 3: Perfectioning<br>*Stabilizing and development of availability* | - Motion technique independent from confounders<br>- Activation of sensomotoric variations<br>- Physical performance gains importance | - Variation (safe skiing in different environmental conditions)<br>- Variability of application of motor skills |

The action approach focuses on the competence of mastering motion skills rather than on learning concrete motion patterns. Thereby, the athlete is empowered to adjust faster to unfamiliar motion tasks in testing his individual range of motion sequences (Schöllhorn, 2005, p. 56).

The main difference between the two concepts resides in the fact that the action approach (also: differential learning) allows improvements in terms of inadequacies and the sensation of the motional differences (Spitzenpfeil et al., 2007, p. 157), while the motor approach regards motional differences with respect to an "ideal motion" as deficiencies. Both concepts can be valuable in the design of a training feedback for skiing (see Table 5-2).

*Table 5-2: Comparison of the two main learning principles with respect to basic criteria of motor learning (Birklbauer, 2006, p. 504). Both concepts can be valuable in the design of a training feedback system in skiing. Possible applications are highlighted grey.*

| *Criteria* | *Motor approach* | *Action approach* |
|---|---|---|
| Basic principle | Learning as improved capability of information perception and -operation | Learning as development of abstract athlete-enviroment interrelations |
| Learning principles | - Sensomotoric learning<br>- Learning of schemes and models | - Interpolation, extrapolation<br>- Self-organization of learning |
| Modes of variation | Predetermined a priori | Differentiation is learned a posteriori |
| Variances of motions | Are avoided | Are immanent for learning process |
| **Example application in Digital Skiing Coach** | **Comparison of forward to backward ratio in turns to „ideal" ratios from professionals** | **Stimulation of extreme body positions in order to improve sensation of body position and ski balance** |

### 5.3.2 Types of feedback in sport and their value to skiing

The importance of information perception and operation was discussed in the preceding section. In this section, a closer inspection of the different characteristics of feedback in sport is presented. For the sport context, the lexicon of sports science provides a good basis for the understanding of feedback (Schnabel & Thiess, 1993, p. 293). Accordingly, feedback is understood as a back-coupling of behavioral effects to the triggering subject. The back-coupling of learning effects plays a dominant role for the learning process in terms of a comparison of consciously or unconsciously anticipated motion routines and the result of the motion. Krug et al. (1998, p. 194) conceptually describe a combined feedback and measurement setup system which appears to be well-suited to the purpose of the Digital Skiing Coach as a skiing technique-based feedback system.

A variety of literature sources define biofeedback as back-coupling of vital, afferent physiological and mental information (Schnabel & Thiess, 1993, p. 177; Beyer, 1987, p. 147; Baumann, 2006, pp. 103f.; Schenk, 1989, p. 8). A previously developed research prototype system which used similar methods as the Digital Skiing Coach has been defined as a "biofeedback system" by other authors (Schaff et al., 1997). Based on the available definitions, the present research can be classified as a biofeedback system.

*Term description*

**Feedback in a measurement setup**

The nature of feedback in a measurement setup is complex technique or fitness training. The execution of motion is objectivized in its environmental and sports technological interaction and eventually provided as feedback to the athlete or trainer within an effective period of time (Krug et al 2004, P. 20).

Extrinsic and intrinsic feedback:

Besides the motion task and the physical activity itself, feedback is essential for a successful motor learning process (Marshall & Daugs, 2003, p. 281) because the learning process itself is based on reception, processing and retention of information (Leirich, 1993, p. 342). Sports science differentiates between two categories of feedback, namely intrinsic and extrinsic feedback (Figure 5-4).

Extrinsic feedback can be provided by trainers or technological feedback systems. Intrinsic feedback is inherent and refers to feedback generated by the sensory organs of the human body. Extrinsic feedback is supplementary information and refers to feedback generated externally, mainly outside the human body. Extrinsic feedback is further subdivided into knowledge of results (KR) and knowledge of performance (KP), meaning that the feedback information relates to the results of a motion task or is about the motion sequence itself (Haase & Hänsel, 1996, p. 51). KP also includes feedback of kinematic and dynamic motion parameters (Newell & Walter, 1981).

In regards to KR, it has been shown that feedback given only when a certain error range is exceeded, for example 10% of the nominal value, leads to a better retention capacity than smaller error ranges (Sherwood, 1988). At the same time, the time period between feedback sessions was reduced with increasing progress. This concept is called bandwidth knowledge of results. For less complex motion sequences, the so-called summary knowledge of results also leads to a better retention capacity compared to single feedbacks (Lavery, 1962; Gable et al. 1991; Schmidt et al., 1989). In average KP studies, the athlete receives an average error regarding the motion sequence after several trials, and in specific experimental setups, this can also lead to better learning effects (Young, 1988).

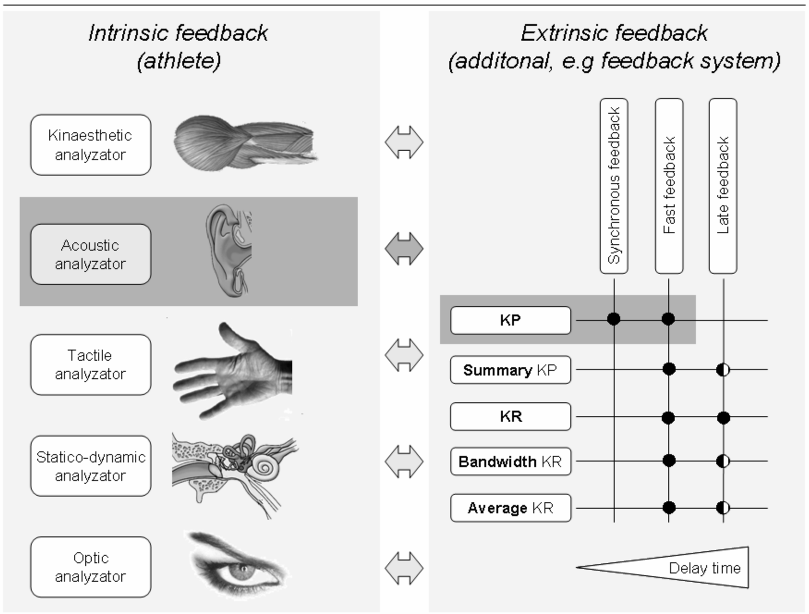



*Figure 5-4: Analyzers of the human body and possible types of extrinsic feedback. Because of the relatively low occupancy on the acoustic analyzer in sport, it is suitable for extrinsic feedback in terms of a training feedback system for skiing. In motor learning, immediate feedback relating to motor skills (knowledge of results = KP) is of particular importance.*

Intensity of feedback:

In generally, more frequent feedback is beneficial at the beginning of a motor learning process and as a skill set improves, the frequency should be reduced (Wulf 1994, p. 110) to avoid a dependency on feedback. The positive and negative effects of feedback with respect to the feedback frequency are summarized in the “guidance hypothesis” as discussed by several authors (Schmidt, 1982, p. 559; Salomini et al., 1984, p. 364; Wulf & Schmidt, 1989, p. 749; Schmidt et al., 1989, p. 357, Winsten & Schmidt, 1990, p. 686; Schmidt, 1991; Wulf, 1994, p. 119f.). Figure 5-4 depicts the connection between the different concepts of extrinsic feedback and the time delay of the feedback. Synchronous feedback is regarded as feedback that is provided during the motion sequence (within several tenths of a second) and fast feedback is typically provided within approximately 30 seconds after the motion sequence has ended. Finally, late feedback is provided beyond short-term perception (Grosser & Neumaier, 1982).

For a sport with such complex motion sequences as skiing, it might be more beneficial to provide feedback as quickly as possible (synchronous feedback). The specific modalities must be elaborated in empirical studies in the course of the system design and evaluation (see chapters 5.6 and 5.7).

Intrinsic mechanisms and their availability for extrinsic feedback in skiing:

To make use of external feedback for learning processes, extrinsic and intrinsic feedback must be linked together in a feedback chain (Maletz, 2007, p. 46). The feedback system (extrinsic feedback) "senses" motion parameters that eventually are analyzed in terms of a technological operationalization. The different senses of the human body can then be used to establish reception of the back loop information from the feedback system. An analyzer consists of specific receptors (sensory organs), afferent nerve tracts (leading to the central nervous system) and sensory centers in different areas of the human brain.

Direct access in terms of feedback can be achieved by linking feedback information to one or more of the five sensory organs (according to Weineck, 2003). First, the receptors of the kinaesthetic analyzer account for muscle control, protection against ligament overstress and the sensing of changes in the joint angles. Further, they are essential for fine-tuning of spatial and temporal parameters of sports activity. Second, the receptors of the tactile analyzer are located beneath the skin's surface and provide haptic information. Third, the vestibular sense organ is situated in the vestibular apparatus of the inner ear and produces information about changes in direction and acceleration. Fourth, the receptors of the optic sense organ feed information about the body's motion and motion of nearby objects and facilitate the optic guidance of sports activity. Finally, the acoustic sense organ receives acoustic information. The execution of the feedback chain is subject to the following five steps (for detailed information see Zariorski, 1968; Krüger, 1982; Lehnert & Weber, 1975; Grosser & Starischka, 1998, p. 93):

1. Perception: stimuli reach the receptor of a sensory organ.
2. Afferent phase: transfer of signals to central nervous system on afferent nerve tracts.
3. Information processing: biochemical processes in the brain define action patterns.
4. Efferent phase: transfer of signals to muscles on efferent nerve tracts.
5. Latency period until muscle activity: delay time because of biochemical reactions between the nerve endings and the muscle fibers.

Generally, it is assumed that faster motor learning can be achieved by acoustic feedback compared to visual feedback (Harrison & Mortensen, 1962; Carlsöo &

Edfeldt, 1963; Leibrecht et al., 1973)). In principal, acoustic feedback can be implemented slightly faster because of the shorter conversion time of the acoustic stimuli into neuronal impulses (Weineck, 2003, p. 420). Other studies showed that the optic feedback led to better results (Lynch et al., 1974) or that no difference can be detected (Blanchard & Young, 1972). It is likely that the effect of a specific type of feedback depends on the nature and complexity of the motion sequence (Hume, 1979, p. 85). The excitation of the sensory organs, the transmission through the nerve pathways to the central ganglions and the subsequent control mechanisms and efferent impulses back to muscle stimulation play an important role with respect to the delay time between stimulus and muscle reaction (Steinbach, 1966, p. 8). Therefore, the overall reaction time not only includes the conversion time of stimuli into neuronal impulses but also accounts for the mechanisms mentioned. In this sense, the reaction time is also dependent on the training state and the age of the athlete. Miles and Cowdry (in Hollmann & Hettinger, 1980, P. 275) observed favorable reaction behavior to optical feedback in athletes between the ages of approximately 20 and 50 years old. Grosser & Starischka (1998, p. 90) published an overview of the response times to acoustic, optic and tactile stimuli and Weineck (2003, p. 420) differentiated reaction time by the training state of the athlete. The results showed that the reaction time to optic stimuli varied between 0.05 seconds for professional athletes and 0.35 seconds for amateurs. The reaction time to acoustic stimuli ranges from 0.05 seconds (world class sprinters) to 0.31 seconds (non-athletes). Weineck specifies average values based on the training state of the athletes of 0.15 seconds and 0.25 seconds for professionals and amateurs, respectively.

Apart from the reaction time, also the effects on learning processes is of core importance when using acoustic feedback. Scaletti (1993, p. 22) defined acoustic feedback in terms of systematic electronic sounds as sonification. Accordingly, sonification is a mapping of numerically represented relations in some domain under study to relations in an acoustic domain for purposes of interpreting, understanding or communicating relations in the domain under study. Compared to verbalization, sonification allows the continuous and correctly scaled display of variabilities in the intensity of a signal, which can be a great advantage for motion feedback in sport. Various studies in performance sports, especially in water sports (e.g. Effenberg & Mechling, 2004; Effenberg, 2004; Effenberg, 1995, pp. 169-174) showed that sonification is not only the activation of a relatively low stressed sensory organ, but led to the some sustainable effects with respect to sports activity:

- Increased awareness and increasing preciseness of dynamic motion sequences.
- Stabilization of motion technique.
- Optimization of motion speed.
- Increasing kinaesthetic sensibility.

Despite the apparent advantage of acoustic feedback, the actual use of the feedback must be considered in deciding which type of feedback is appropriate for the design.

As mentioned before, this strongly depends on the complexity of the motion task. In general, the kinaesthetic, tactile and vestibular sense organs interact and complement each other during sports activity. They strongly influence the quality of motion sequences while their specific importance can vary depending on different sports (Meinel & Schnabel, 2006, p. 48). The optic analyzer is also essential in most sports.

As for alpine skiing, the complexity of the motion itself and a complex interaction between the athlete and the environment represents a great challenge for the optic sense organ of the athlete. Currently, acoustic feedback, in the form of verbal assistance, is used exclusively by ski instructors during ski classes such that, and in addition to the abovementioned reasons, sonification seems to be an appropriate way to provide additional information about skiing technique.

### 5.3.3 Summary

The literature findings suggest that technique feedback in sport can be a beneficial method to enhance the learning process. Four elements are important for system design: the determination of the nominal and the actual values to be provided by the feedback, the content of the feedback, the update rate of the feedback and finally the reaction time. The ventral-dorsal shift of the skier during turns is a clear application for knowledge of performance feedback because of the emphasis on the motion sequence. The feedback itself should be carried out as acoustic feedback because of the relatively low stress of the acoustic analyzer in skiing. Previous studies in performance sports have shown that acoustic feedback can lead to significantly reduced failure rates and improved motion technique. Further implementation of acoustic feedback will be described in the context of system design in chapter 5.6. The system should provide synchronous feedback during the course of the skiing activity while at the same time accounting for the complexity of ski turns. A delayed feedback would most likely lead to poor memorization and result in fewer and slower improvements.

## 5.4 Physical and biomechanical basics of ski turns

To understand the underlying motion mechanisms of skiing vis a vis skiing motion tasks, a brief introduction into the theoretical basics of ski turns is necessary. This information served to clarify research question four:

4. What are the basic characteristics of skiing technique?

Specifically, the relevance of load changes on the ski during turning resulting from a shift of the body’s center of gravity will be expanded upon. It is the basis for the generation of feedback algorithms which were incorporated in the Digital Skiing Coach.

### 5.4.1 Physics of ski turns

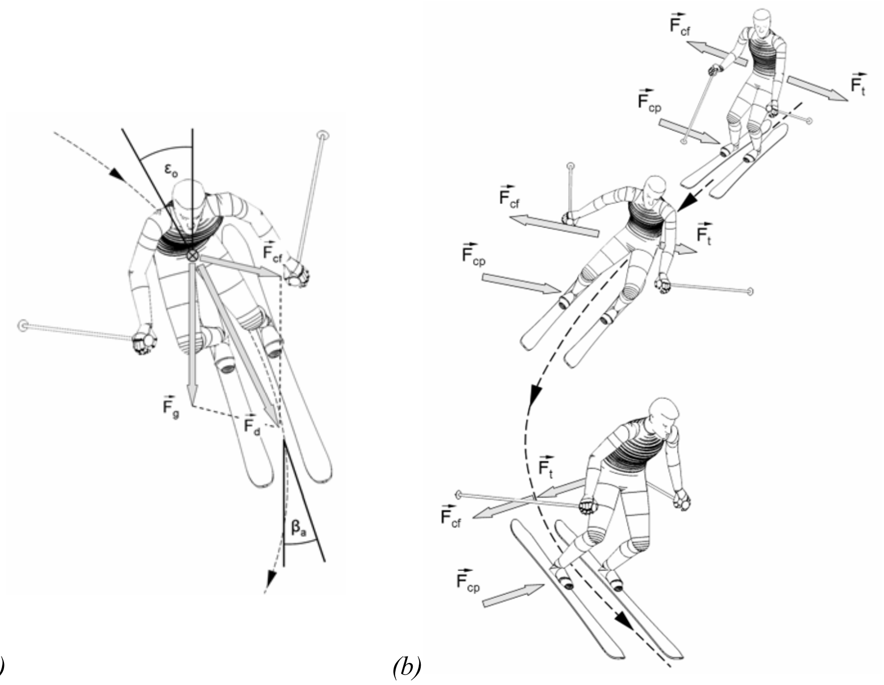
The following outline is based on Müller's (1991) publication about the biomechanics of alpine skiing. Even though skiing style has changed towards "carving", it should be noted that the basic physical principles of skiing remain the same (Wörndle, 2007). Skiing education still teaches driving turns with parallel skis and focuses on a mastering of different environmental conditions. Biomechanically speaking and regarding the position of a skier on the slope, there are two main positions: skiing schuss or diagonally with turns. Schuss refers to a straight downhill path, while diagonally refers to the movement of the skier traversing a slope and incorporating turns. Schuss and traversing are not very challenging movements while turns require a complex interaction of motor skills. Here, only turns will be discussed in detail because of their relevance in the learning process.

Dynamic lateral forces in skiing: First, identifying the center of gravity of the entire system is essential in understanding the mechanics of turns. Thus, it is important to understand that the system not only consist of the skier, but encompasses the skier's body and all sports technology attached to the skier (most notably the skis and ski boots). This is of specific relevance in skiing because the equipment is heavy and attached to the ends of the extremities. Therefore, the center of gravity of the system will be considerably different from the center of gravity of the skier. In the following discussion, only the system's center of gravity is considered (according to Wörndle 2007, p. 96). The system's center of gravity can be regarded as a fictional, dynamically changing location to which the entire mass of the system is reduced and which is the imaginary point of action for all external forces (according to Schnabel & Thiess 1993, p. 479; Lind & Sanders 1996, p. 52). This notion is fundamental for the mechanics of turns.

Skiing is possible because the edges of the skis cause a counterforce to the system weight and inert forces of the system through interaction with the snow (Figure 5-5). The most important dynamic forces are the following:

- Downhill-slope force ($F_d$)
- Normal force ($F_n$)
- Transverse force ($F_t$)
- Centrifugal force ($F_{cf}$)
- Centripetal force ($F_{cp}$)

The downhill-slope force is a function of the system weight and the slope angle (downtilt). According to simple physical principles, with increasing downtilt ($\alpha_d$) (not depicted in Figure 5-5) the downhill-slope force ($F_d$) will increase while the normal force ($F_n$) will decrease. The centrifugal force ($F_{cf}$) is a function of the system weight, downhill speed and turn radius. To ski a turn, the athlete must produce a centripetal force ($F_{cp}$) on the edges of the skis. Together with the centrifugal force, this produces a turning moment (Mt) around the longitudinal axis which acts to tilt the skier towards the outer curve. The adjustment of an appropriate orientation angle




*(a)* *(b)*

*Figure 5-5: Forces on the system's center of gravity (a) and the motion sequence of a turn regarding equilibrium of forces (b).*

($\varepsilon_o$) can compensate this turning moment and facilitates a dynamic lateral balance during the turn. The orientation angle is a function of the downhill velocity ($v_d$), turn radius ($r_t$), downtilt ($\alpha_d$) and azimuth angle ($\beta_a$). The dynamic change of these forces during the sequence of a turn is depicted in Figure 5-5 (b). The skier is connected to the skis by the mechanics of the ski binding and is therefore able to transfer motional changes to changes in direction and complete turns. The system presented here relies on this interface between the skier and the skis to draw conclusions about skiing technique.

Dynamic longitudinal forces in skiing: Thus far we have only considered lateral forces. However, to fully understand the dynamics of a ski turn, the longitudinal balance must also be considered. The assumption that alpine skiing is characterized by the situational adaptation of a so-called "basic position" according to downtilt and environmental conditions is generally accepted (Wörndle, 2007, p. 97). The basic position is defined as a balanced longitudinal position in terms of a ventral-dorsal (forward-backward) shift of the system's center of gravity. The lateral balance is usually adjusted instinctively by the skier. However, properly adjusting the longitudinal balance is often a problem for both beginner and experienced level skiers (Scheiber, 2004) and is the main topic of interest in the present research. The necessity of shifting one's balance along the longitudinal axis becomes clear when comparing a skiing turn while entering versus exiting steeper sections of a slope (Reinboth, 2006, p. 18). To maintain a balanced position, the skier must shift the system's center of gravity towards the forefoot. Upon exiting a turn, the system's center of gravity must be shifted backwards onto the heels (Figure 5-6).

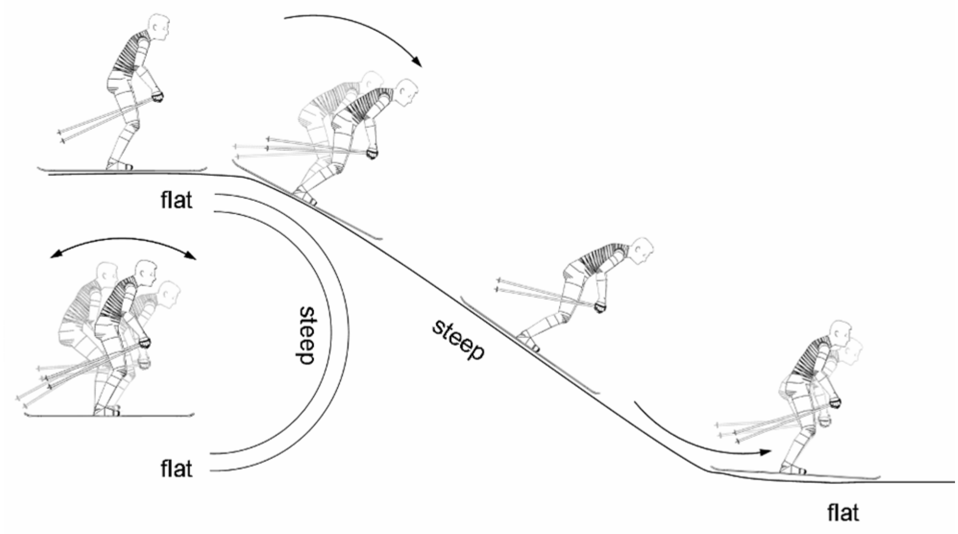



*Figure 5-6: Ventral-dorsal shift in a ski turn (similar to Skilehrplan Praxis, 2006).*

### 5.4.2 Influence of motion

In the previous section, it has been shown that physical principles must be satisfied by the adjustment of dynamic balances during the course of a ski turn. The question arises of how these balances can be achieved by the skier. The German skiing curriculum provides a suitable answer for this question. Any motion carried out by the skier leads to a change of the system's center of gravity and therefore changes the skis' load distribution on the snow (Reinboth, 2006, p. 11). Thus, the skier can take advantage of this change in load distribution to accomplish the physical principles of ski turns mentioned above. Ski control and changes in direction are mainly achieved by using inner forces (muscles, fibers and ligaments) to move the body or by control mechanisms that result from external forces in terms of interactions of the ski and the environment (the friction between ski and snow). In reality, skiing is a combination of both mechanisms (Wörndle, 2007). To perform a ski turn, either the external forces that result from edging must be reduced (gliding) or movements must be carried such that the edging itself leads to a change in direction (Glitsch, 2001, p. 141). In the following paragraph, the basic movements and their effect on ski loading will be explained.

Movements along the longitudinal axis of the ski: The ventral-dorsal shift of the system's center of gravity results in shifting the weight to the forefoot or the heel (Figure 5-7). The effect is a change of the ski loading on the ski-tip or the ski-end. A balanced loading of the foot is called the central position. The effect is an even ski loading along the ski length which facilitates ideal gliding. Ventral-dorsal shifts are important for the introduction and exit of ski turns.

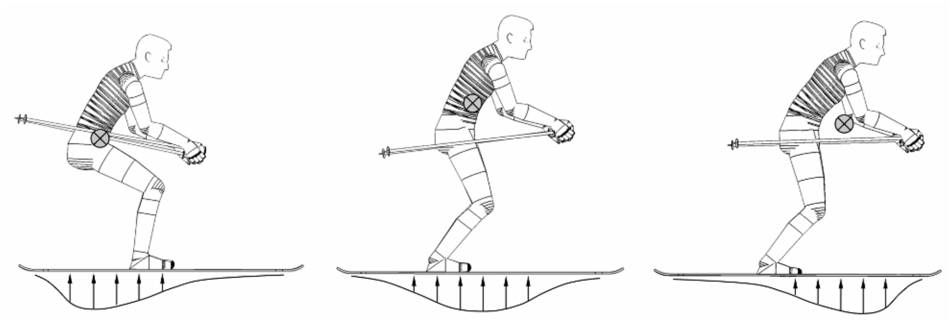


*Figure 5-7: Ventral-dorsal shift of the system's center of gravity and changing ski loading.*

Movements lateral to the longitudinal axis of the ski: Two movements are distinguished in the literature to control sideways movements: tilting and bending.

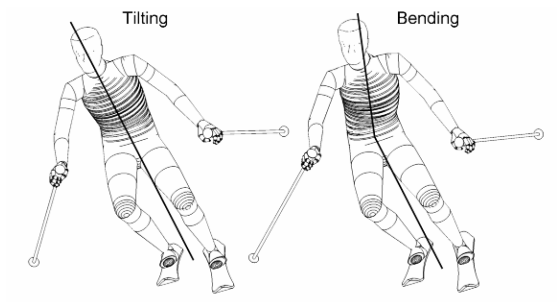



*Figure 5-8: Tilting and bending in ski turns to enable edging and to maintain body's balance.*

While tilting mainly serves to put the skis on edge and change the load between the left and right ski during turns, bending allows for the regulation of the body's balance and fine tuning of edging and load changes (Figure 5-8).

Movements normal to the longitudinal axis of the ski: Movements normal to the ski axis (Figure 5-9) lead to a change in the magnitude of the ski loading because the effects of inertia ($F_{in}$) are added to the normal force, $F_n$. This effect facilitates the introduction of turns.

Rotary movement around the normal axis: Movements around the normal axis are essential for ski turns in introducing and supporting the abovementioned movements, but do not cause considerable changes in ski loading.

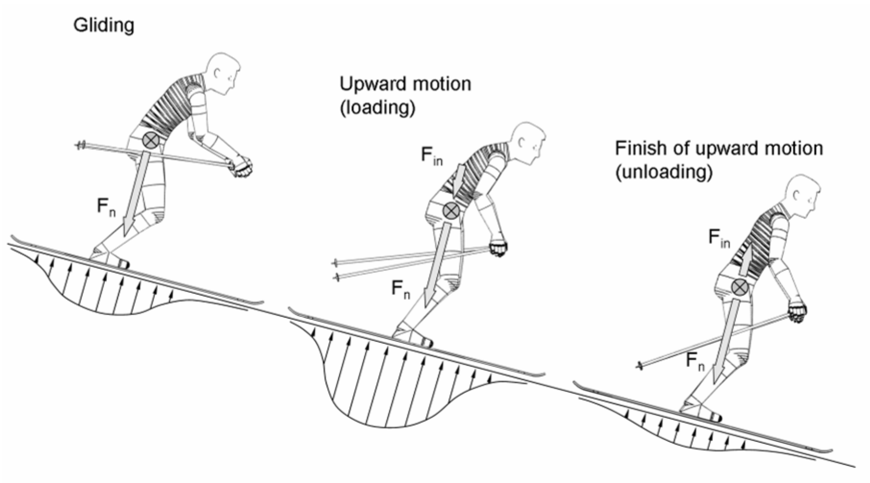



*Figure 5-9: Movements normal to the ski axis and their effect on the ski loading.*

### 5.4.3 Summary

The appropriate ventral-dorsal shift of the system center of gravity is an important starting point of learning ski turns and therefore must be a basis for a feedback system which aims to improve skiing technique. Also, transversal body shifts are an important aspect in the mechanism of a ski turn. The described mechanisms will serve as a basis for further investigations in the quantification of skiing technique in the following section.

## 5.5 Feasibility of sole pressure measurement for training feedback in skiing

In the present chapter, preliminary research with respect to the design and evaluation of the Digital Skiing Coach is discussed. This preliminary research was used to address research question five.

5. Can basic characteristics of skiing technique be operationalized in a way such that motion patterns can be displayed by a sole pressure measurement system for leisure skiing?

The measurement of the sole pressure distribution is a commonly used skiing technique training method in ski racing (e.g. Spitzenpfeil et al., 2004, pp. 193ff; Kaps et al., 2001; Lüthi et al., 2005). Schaff (1997) developed a conceptual prototype of a training feedback system for skiing that was based on sole pressure measurement. A considerable amount of pressure distribution data is available from Schaff's studies. The problem with utilizing sole pressure data is that expertise in skiing technique is required to analyze the data and provide valuable feedback to the athlete. Further, the setup of the measurement method is relatively complex (see explanation of methods below). Hence, the sole pressure measurement approach used to date is only feasible in professional sports where a personal trainer and a scientific support team are available. This is most likely the reason why valid data concerning the sole pressure distribution of beginner or intermediate skiers could not be identified. The present feasibility study was conducted to determine whether the sole pressure distribution method can be used to evaluate skiing technique and to define opportunities for implementation of the method with respect to training feedback in leisure sports.

### 5.5.1 Approach and research questions

A stepwise approach was developed to address research question five as described above (Figure 5-10). In addition, experts from the field of science in ski racing were interviewed concerning the practicability of the current research purpose. Their comments served as input for the study design. Finally, data analysis was performed to investigate the applicability of sole pressure measurement for technique training in leisure skiing.

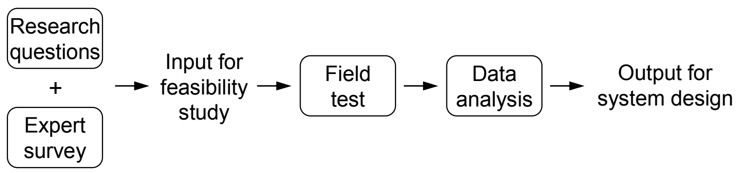



*Figure 5-10: Approach for the feasibility study.*

Basic characteristics of skiing technique were discussed in chapter 5.4. These characteristics should be monitored and analyzed by consulting sole pressure distribution data. Based on this requirement, the following questions were established:

5.1 Is it possible to obtain information about basic motion patterns in skiing by only observing the sole pressure distribution?
To employ sole pressure distribution data for a training feedback system, it is essential that basic characteristics of skiing technique be obtained only from the data without requiring additional motion monitoring.

5.2 Is it possible to distinguish motion patterns of intermediate skiers from motion patterns of professional skiers?
A variety of systematic and individual influencing factors complicate the comparative analysis of sole pressure distribution in skiing (e.g. loads which discharge through the shaft of the ski boot). It must be verified whether the

characteristic motion patterns of professional skiers and intermediate skiers can be distinguished.

5.3 What number of sensors and which sensor areas are needed to draw conclusions about basic characteristics of skiing technique?
With respect to economic system design, it is important that information about skiing technique can be obtained from a reduced set of sensor data.

5.4 What are ideal pressure patterns for the basic skiing styles?
The system design incorporates an expert system[7] that compares the athlete's sole pressure distribution to the ideal sole pressure distribution of professional skiers. Therefore, a database containing the data from professional skiers that corresponds to the database was generated from the intermediate skiers' data had to be generated.

In addition, several experts' opinions were collected for the purpose of obtaining a proposition about the practicability of the present research and for additional input on the design of the field test. Three designated experts who have previously worked with sole pressure distribution in performance sports participated in the meeting: Dr. Peter Spitzenpfeil (research in ski racing and training diagnostics), Andreas Huber (Olympic performance center Munich, research in ski racing) and Charly Waibel (scientific trainer of the German ski world cup team). The experts were presented with the research questions in an open interview on November 28th, 2007.

All three experts indicated that basic conclusions and direct training feedback about skiing technique (e.g. ventral-dorsal position, load distribution between the legs and the ski edges) would be possible only by sensing the pressure distribution on the ski-boot sole. The information obtained from the pressure distribution data would be beneficial for beginners and intermediate skiers introduced to new skiing styles as well as for an overall improvement of skiing technique. The generation of appropriate feedback should be possible by referencing the dynamic sole pressure distribution during skiing to a static load situation.

### 5.5.2 Study design, materials and methods

Study design and sample group:

The field test was designed as a cross-sectional, explorative case study. The goal was to collect information about the sole pressure patterns of skiers with different skiing skills and compare the pressure patterns. Selected professional and intermediate skiers (see Table 5-3) were equipped with a sole pressure measurement system and performed a test cycle on ski slopes with six different exercises.

[7] Expert system here is defined as the validated knowledge base of a software program which compares input data to the data of the knowledge base.

*Table 5-3: Characteristics of the sample group.*

| *Sample group parameter* | *Specification* |
|---|---|
| Size and participants | N = n = 6 |
| Age | $\bar{x}$= 31.8 y (SD = 10.8) |
| Gender | 1 female, 5 male |
| Skiing skills | 3 professional skiers (ski instructors)<br>3 intermediate skiers (qualitative estimation) |

The skiing styles were varied in the exercises. Furthermore, the steepness and general characteristics of the ski slopes were chosen to reflect the skiing style to be performed on that portion of the exercise. Hence, the independent variables were skiing style, steepness of the slopes and ski length, which were systematically varied. The dependent variable, the sole pressure distribution, was recorded during all exercises. Some additional exercises were performed by the study investigators to produce input parameters for the system design and included jumping to observe the maximum range of loads and skiing super-G turns. The review of the skiing biomechanics literature (chapter 5.4) introduced claims that should be tested in the field test with respect to research questions 5.1 and 5.2. The parameters of the study setup are summarized in Table 5-4.

Control of confounding factors:

The control or elimination of confounding factors is generally difficult in field tests. Some precautions were taken to control the most important confounding factors that may influence the results of the study. Weather conditions are a critical factor in all field tests because it cannot be controlled. Fortunately, during all three days of the field test, weather conditions were nearly constant (see Table 5-4). Second, all of the test subjects used the same model of test skis and bindings; however, no standardized ski boots were used. Finally, advice was given orally to the subjects in a standardized way, i.e. all subjects were introduced to the general test procedure and the exercises.

Materials and methods:

A Novel Pedar-X® system was used to record the sole pressure distribution in the ski boots. The system is commonly used for scientific analysis in ski racing and is considered a standard tool in this area of research. The system consisted of a sensor insole with 99 capacitive pressure sensors per sole, covering the entire sole area. The sensor area is approximately two square centimeters and was recorded at a frequency of 100 Hz. The sensor insoles are connected to a data acquisition device via cables. A trigger box is used to start and stop data acquisition. After the test cycles, the data was then transmitted to a personal computer for post-processing. In addition to collecting sole pressure data, the test cycle exercises of all subjects were videotaped using a digital three-chip video camera for post-test motion analysis. Data processing was conducted using Ikemaster® analysis software that enables the user to match and align sole pressure distribution data with video data. For synchronization of the sole pressure and video data, the subjects performed a slight jump prior to beginning each exercise. A certified ski instructor was engaged for the qualitative analysis and assessment of the motion patterns (expert rating).

*Table 5-4: Parameters of the field test for evaluating basic characteristics of skiing technique*

| *Parameter* | *Specification* |
|---|---|
| Statements (working hypotheses) | 1. The more loading is applied to the outer/inner edge of the ski, the higher/lower is the overall pressure on the outer/inner side of the ski boot sole.<br>2. The more the skier moves forward/backward, the higher is the pressure on the forefoot/heel area of the ski boot sole.<br>3. It is possible to distinguish left and right turns by the overall load on the inner/ outer ski boot sole. |
| Skiing styles | - Skidding short turn (turns on medium steep slope ~25°, radius ~2m)<br>- Skidding medium long turn (turns on medium steep slope ~20°, radius ~5m)<br>- Skidding long turn (turns on medium steep slope ~15°, radius ~15m)<br>- Carving middle turn (turns without skidding, medium steep slope ~15°, radius ~20m) |
| Skis<br><br>Binding and plates | - Nordica Dobermann cs pro, 164cm, radius 12m<br>- Nordica Modified, 178cm, radius 18m<br>- Marker N0312, Xbalancesystem |
| Location and date | Zugspitze, Germany: plateau<br>Dec. 20th 2007 to Dec. 22nd 2007 |
| Conditions | - Snow: dry, firm, old, prepared<br>- Weather:sunny, T = -5°C – +1°C |

### 5.5.3 Execution and data analysis

At the beginning of each test cycle, the subjects were equipped with the sole pressure measurement system and introduced to the purpose of the study. On the ski slopes, a ski instructor orally presented the exercises to the subjects. Before beginning the exercises, it was necessary to zero the pressure measurement insoles. This was accomplished by having the subjects lift each leg independently to remove pressure on the sensors, resulting in a standardized presetting of all subjects.

A qualitative analysis of the test cycles was performed by assessing and matching the motion patterns obtained from the video data with the sole pressure measurement data. The resulting information was used to address research question 5.1. For quantitative analysis of the sole pressure distribution data, the 99 sensors of the sensor insole were clustered into four areas comprised of 15 sensors each (see Figure 5-11 and description below why 39 of the sensors were not considered). The clusters corresponded to the basic motion patterns to be investigated (ventral-dorsal ratio, medial and lateral loading and overall loading ratio of inner ski versus outer ski).

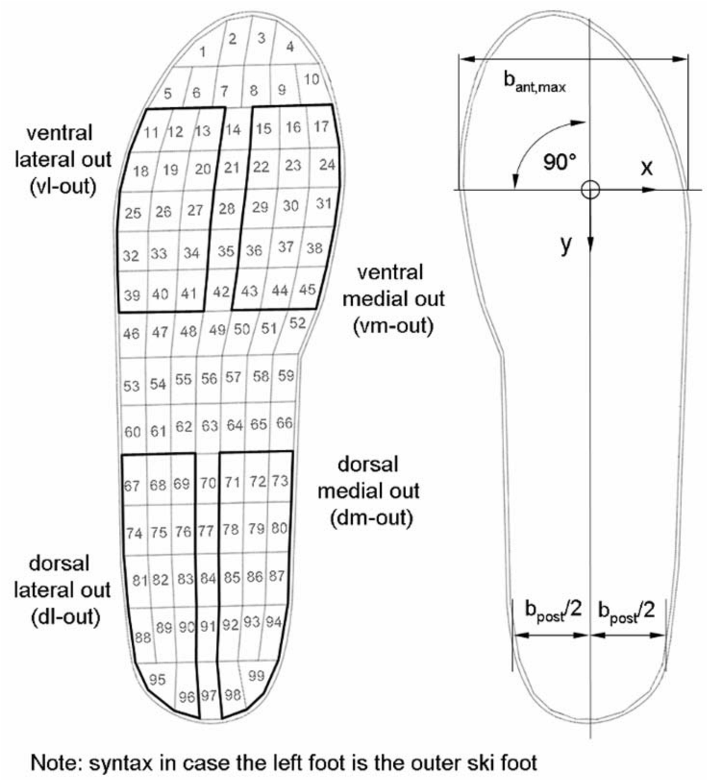



*Figure 5-11: Sensor clusters for the calculation of balance ratios and coordinate system for the determination of sensor positions.*

The values of the individual sensors were summed such that the ratios could be calculated by comparing the summations, S, of the clusters as follows:

$$S = \sum_{i=1}^{15} S_i \tag{5-1}$$

The ventral-dorsal ratio of an outer ski sole ($Q_{vd\text{-}out}$), for example, was then calculated as the quotient of two summations (see also for a clarification of the syntax):

$$Q_{vd\text{-}out} = (S_{vm\text{-}out} + S_{vl\text{-}out}) / (S_{dm\text{-}out} + S_{dl\text{-}out}) \quad (5\text{-}2)$$

where $Q_{vd\text{-}out}$ = ventral-dorsal load ratio of the outer ski sole
$S_{vm\text{-}out}$ = load on the ventral medial cluster of the outer ski sole
$S_{vl\text{-}out}$ = load on the ventral lateral cluster of the outer ski sole
$S_{dm\text{-}out}$ = load on the dorsal medial cluster of the outer ski sole
$S_{dl\text{-}out}$ = load on the dorsal lateral cluster of the outer ski sole

Figure 5-12 depicts the reference directions with respect to the specified nomenclature; this nomenclature is used in all subsequent sections as well.

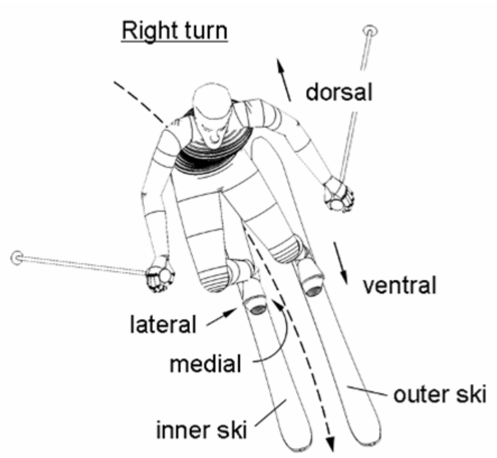


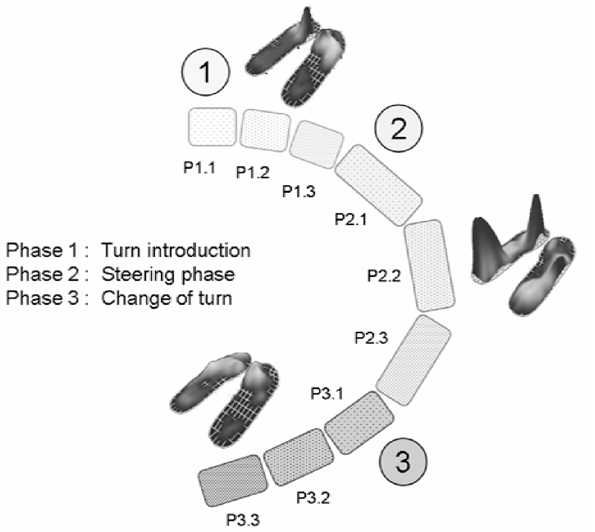

*Figure 5-12: Indication of directions in skiing and with respect to ski loading.*

The clusters were built based on assumptions that were affected by considerations regarding the validity of the results and the system design. By defining sensor clusters that are associated with the areas relevant to the motions of skiing instead of using all of the clusters, the data can be used later for the design of a feedback system. The sensor data from the toe area was excluded because the pressure distribution is highly influenced by individual conditions and by the fact that the sensor insoles did not precisely fit all foot sizes. The sensors in the area under the arch of the foot were excluded because the electronics would likely be placed in this area in the final design, restricting sensor placement in this portion of the insole. It was observed that the variance of sensor loading was very low. The longitudinal center row of sensors was excluded to preserve symmetry of the cluster sizes.

Depending on the research question to be addressed, the pressure distribution data of all subjects or only subjects from a specified skill level was used to generate mean values of either single turns or complete downhill runs of a particular skiing style.

The data was segmented into single turns and normalized by time and the maximum mean pressure value (i.e. the maximum values were set to 100 % load). An individual turn was identified by the characteristic “change of overall load from outer ski to inner ski” and verified by using the related video sequence.

The reference pressure distribution data from the professional skiers’ was generated (research question 5.4) by segmenting individual turns into turn phases and by calculating the characteristic ratios for each phase. Turn phases were identified by systematically setting 5 % intervals on the time scale forward and backward from the change of turn and by an even distribution of sub-phases. The changes of turns were




| *Turn phase* | *Time fraction (% of entire turn)* |
|---|---|
| 1.1 | 5.6 |
| 1.2 | 22.1 |
| 1.3 | 5.5 |
| 2.1 | 1.3 |
| 2.2 | 30.9 |
| 2.3 | 1.3 |
| 3.1 | 6.5 |
| 3.2 | 20.3 |
| 3.3 | 6.5 |

*Figure 5-13: Segmentation of ski turns for the calculation of reference data from professional skiers (left). The fractions of each turn phase with respect to an entire ski turn were calculatedfrom the data sets as mean values (right).*

identified in the pressure patterns as the point in time when the load shifted from the former outer ski to the new outer ski. Figure 5-13 depicts the sub-phases.

Determining the sensor positions that display the motion patterns of interest is an important feature for the system design and is based on Spearman’s correlation coefficient. Each single sensor value within a cluster was correlated to the summation value of the very cluster for a single downhill. The conditions for drawing a correlation are satisfied because the pressure data is interval scaled data and the coherence between both variables (the value for the single sensor and the summation value of the cluster) is linear. The Spearman correlation was chosen because the data does not follow a Gaussian distribution.

The correlation was calculated as follows:

$$r_s = 1 - \frac{6\sum_i d_i^2}{n(n^2 - 1)} \tag{5-3}$$

with $d_i = rg(x_i) - rg(y_i)$

$d$ := difference between the ranks of x and y of a sample

$n$ := number of pairs of values in a sample

Table 5-5 shows an example correlation for a carving turn, including the correlation analysis for all eight clusters. The three sensors with the highest correlation coefficient are highlighted. Further, a weighed assessment was made with these top three ranking sensors for each downhill run of all subjects, i.e. for all skiing styles. The sensors were rated with respect to their ranking in descending order, with the values three, two and one. All other sensors were excluded.

In evaluating these rankings for all data sets, a value of importance ($I_i$) was calculated relating the sensibility of each sensor to motion patterns in skiing examined in this study. Finally, the sensors, with their corresponding value of importance, were reduced to a single point S(x,y), with x and y being the coordinates of the geometric center of each sensor. These coordinates represent the location that corresponds best to the variances in a specific cluster. Determination of the point was accomplished by drawing a metric raster and a coordinate system across the sensor insole's surface area (see Figure 5-11, right) and calculating the center of mass as follows:

$$x_s = \frac{1}{I}\sum_{i=1}^{15} x_i I_i \tag{5-4}$$

with $I = \sum_{i=1}^{15} I_i$ and $x_s$ := Coordinate sensor position (y accordingly)

*Table 5-5: Example for correlation of single sensor data to cluster data*

| left-front medial (lfm) | | left-front lateral (lfl) | | left-back medial (lbm) | | left-back lateral (lbl) | | right-front medial (rfm) | | right-front lateral (rfl) | | right-back medial (rbm) | | right-back lateral (rbl) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | corr | # | corr | # | corr | # | corr | # | corr | # | corr | # | corr | # | corr |
| **25** | **0.9774** | **30** | **0.9921** | **82** | **0.9955** | **93** | **0.9957** | **26** | **0.9786** | **30** | **0.9930** | **82** | **0.9896** | **92** | **0.9948** |
| **26** | **0.9772** | **37** | **0.9920** | **83** | **0.9926** | **85** | **0.9923** | **34** | **0.9617** | **37** | **0.9919** | **81** | **0.9860** | **93** | **0.9947** |
| **19** | **0.9706** | **23** | **0.9894** | **89** | **0.9836** | **92** | **0.9918** | **25** | **0.9611** | **23** | **0.9851** | **83** | **0.9821** | **85** | **0.9915** |
| 34 | 0.9646 | 22 | 0.9862 | 81 | 0.9827 | 86 | 0.9894 | 27 | 0.9582 | 36 | 0.9838 | 76 | 0.9749 | 98 | 0.9857 |
| 27 | 0.9534 | 29 | 0.9832 | 90 | 0.9787 | 94 | 0.9877 | 33 | 0.9538 | 29 | 0.9809 | 89 | 0.9713 | 86 | 0.9831 |
| 33 | 0.9534 | 36 | 0.9829 | 76 | 0.9693 | 98 | 0.9874 | 19 | 0.9121 | 22 | 0.9743 | 90 | 0.9661 | 94 | 0.9781 |

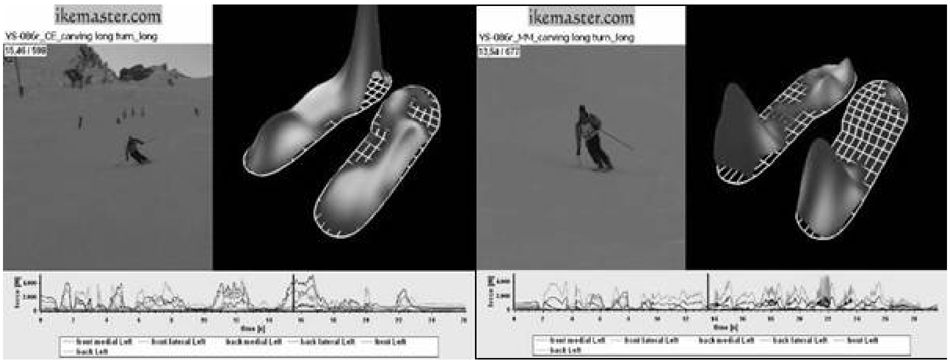
### 5.5.4 Results and discussion

Research question 5.1: Is it possible to obtain information about basic motion patterns in skiing by only observing the sole pressure distribution?

Figure 5-14 (top) shows a screenshot which demonstrates how the sole pressure distribution data and the video sequences were compared. The video image provides a reasonable idea of the specific body position of the skier. Figure 5-14 (bottom) illustrates the clear differences in skiing technique of differently skilled skiers. While the professional skier is able to shift the load forward on the outer ski for turn introduction and display a balanced ventral-dorsal ratio in the steering phase, the intermediate skier shows a clear tendency to dorsal ski loading. Because skiing technique is based largely on the skier's ability to steer the skis by adjusting loads, the relationship of body shifts and sole pressure distribution had to be determined. The qualitative comparison of sole pressure distributions and video sequences suggested the feasibility of extracting information about the quality of the skiing technique for both intermediate and professional skiers. The shifts of the skiers' bodies seen in the video corresponded to the recorded load distribution on the sensor insoles. Specifically, the following corresponding events could be verified regarding the basic characteristics of skiing technique.

- Dynamic transversal movements during the turn phases result in alternating charge and discharge of the corresponding sensor insoles.
- The ventral and dorsal movements of the skier's body during turns results in a corresponding change of load on the sensor insoles.
- Snow resistance, which is exhibited by increased edging of the skis (mainly in the turn introduction phase), is displayed well on the sole pressure distribution.
- Body balance (central position) is displayed well on the sole pressure distribution.

The present measurement setup did not allow identifying the body positions and skiing styles that are associated primarily with the abovementioned discharge of loads by the ski-boot shaft or quantifying the effect. A force measurement ski binding used in combination with the sensor insoles would serve to address this problem. Several publications stated that a major problem of the sole pressure measurement for indicating the skier's center of gravity is the discharge of loads by the shaft of the ski boot (e.g. Schaff & Senner, 1996; Schaff & Senner, 1998). However, the use of sole pressure distribution data for analyzing skiing technique has previously been verified with use in ski racing training, but its value for analyzing intermediate skiers has not been previously addressed.



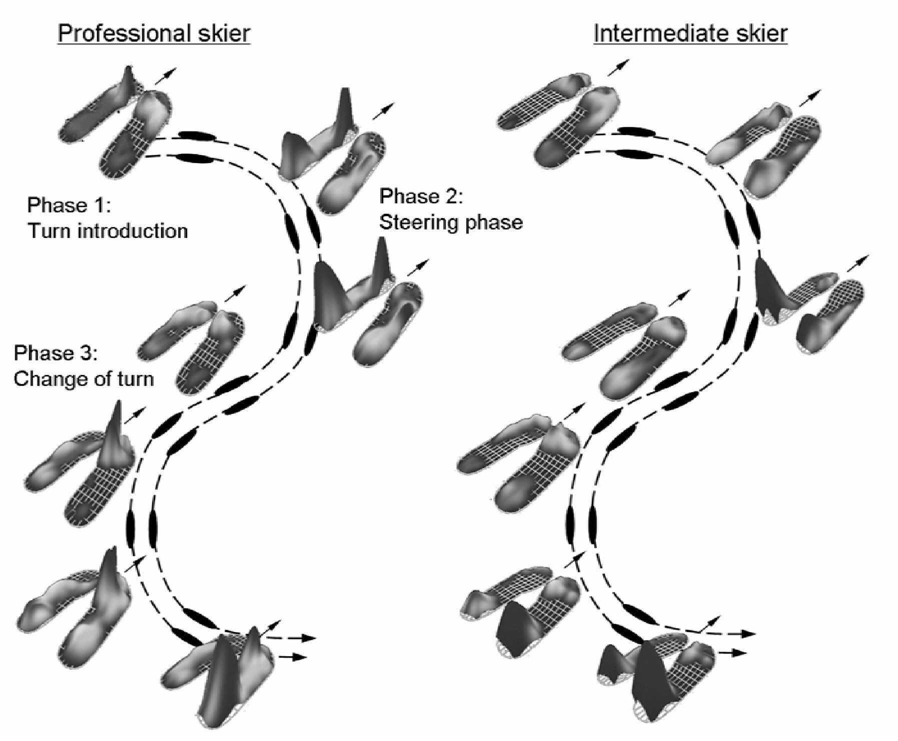




*Figure 5-14: Motion sequence from a professional skier (left) and an intermediate skier (right).*

Research question 5.2: Is it possible to distinguish motion patterns of intermediate skiers from motion patterns of professional skiers?

To answer this question, the main characteristics of skiing technique for the different skill levels were compared. As summarized in Figure 5-15, twelve individual ski turns were analyzed for each subject and mean values were calculated. There is a clear difference in the characteristics of skiing technique and in the skiing styles with respect to the skill level of the skiers. To further illustrate these differences, the difference between the delta value of each value pair of the professional skiers' data (Figure 5-15) and the delta value of the corresponding value pair from the intermediate skiers' data was calculated. The results showed which characteristic of skiing technique and which skiing style deviate the most with respect to the skill level. Differences where the underlying value pairs were switched are shown as negative values (see Table 5-6). The most outstanding differences are shown in bold font.

*Table 5-6: Deviation matrix of skiing technique characteristics of professional skiers compared to those of intermediate skiers. The higher the value, the more prominent was the difference between professional and medium skilled skiers. Contrary and dominant characteristics are highlighted*

| *Skiing style →* <br> *Characteristic ↓* | *Short turn* | *Middle turn* | *Long turn* | *Carving* |
|---|---|---|---|---|
| Ventral-dorsal ratio | **-16.0** | **-6.1** | **-70.8** | **-66.3** |
| Outer vs. inner ski ratio | **71.3** | 23.7 | 36.9 | 4.5 |
| Edging ratio | 14.4 | 3.4 | 26.7 | 25.8 |

Although this data was not statistically evaluated (only six subjects), it provides a good overview of the main deficiencies of intermediate skiers. Most notably, the deviation in the ventral-dorsal ratios were not only considerably higher for all skiing styles (except for the skiing style "middle turn"), but also inverted – that is, the intermediate skiers put too much load on their heels while the professional skiers managed to properly shift in the ventral direction. This is another indication that this aspect of the turn must be emphasized in technique training. Another striking outcome is the very large difference in the inner versus outer ski loading during short turns. The professional skiers manage to apply an equal load to both skis while the intermediate skiers put too much load on the outside ski (see also Figure 5-15). Based on the data, it appears that the quality of skiing technique can be assessed by means of sole pressure distribution in the ski boot sole.

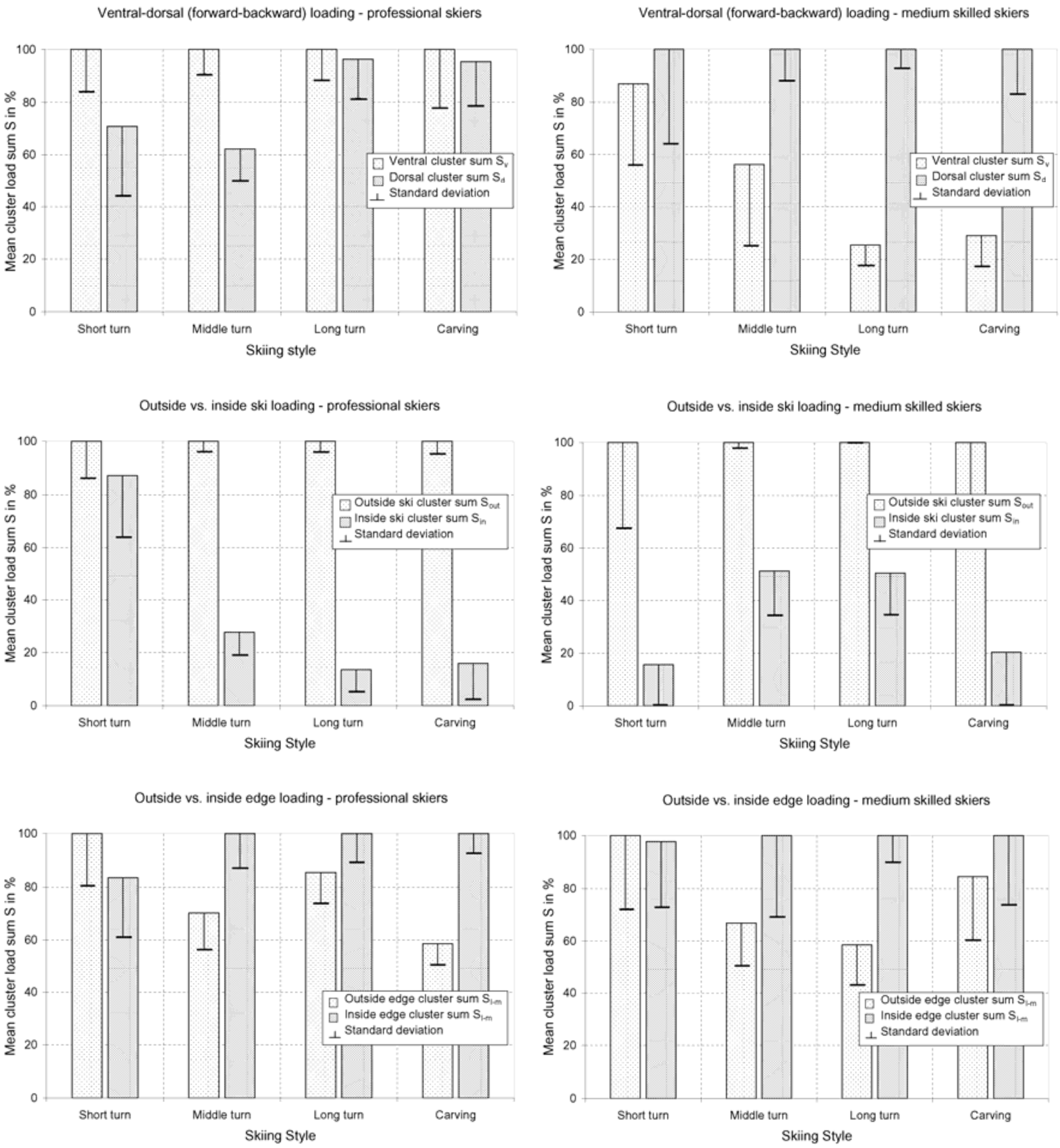
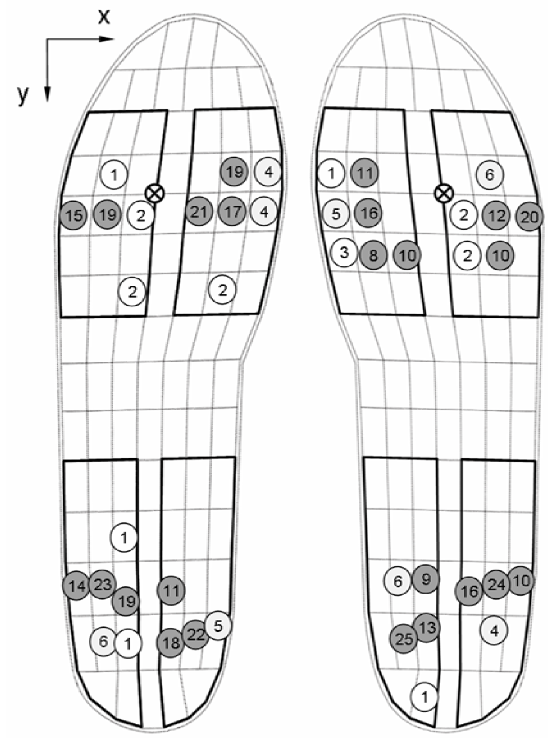



*Figure 5-15: Characteristics of skiing technique of professional skiers compared to those of intermediate skiers. The graphs indicate the mean cluster loading values S in % that refer to the particular skiing styles carving, skidding long turn, skidding middle turn and skidding short turn. The dominant cluster load S was normalized to 100%, respectively, to illustrate the differences.*

Research question 5.3: What number of sensors and which sensor areas are needed to draw conclusions about basic characteristics of skiing technique?

Figure 5-16 (left) depicts the results of the analysis of sensor data regarding the importance of an individual sensor for the detection of basic motion patterns in skiing. The numbers displayed on the individual sensors represent the overall importance I calculated for that sensor. The sensor position was calculated as explained in chapter 5.5.2. The table in Figure 5-16 (right) gives the coordinates of the four sensors used in the present work to detect ventral and dorsal motion as well as edging and load distribution between the left and right feet. The measurements were normalized by sole length and width. For a specific sole size, these coordinates are multiplied by the respective sole length and width. Also, prefixes are not noted because the prefix changes for left and right sole. The sensor sizes for system design were subsequently calculated based on the contact areas of the present sensor insole, as presented in chapter 5.6.




⊗ **Relative point of origin**

| Sensor | relative Position x | relative Position y * |
|---|---|---|
| ventral lateral | 0.095 | 0.035 |
| ventral medial | 0.093 | 0.022 |
| dorsal lateral | 0.056 | 0.585 |
| dorsal medial | 0.056 | 0.588 |

*** Relative positions have to be multiplied with the respective sole length and width**

*Figure 5-16: The most important single sensors in the four sensor clusters regarding basic characteristics of skiing technique (left) resulted from the correlation analysis. They display best the characteristics of skiing technique in a reduced sensor setup. The relative sensor positions (right) in such a reduced sensor setup are related to the relative point of origin of the insoles and were determined with a center of mass calculation on the basis of the single sensor importances.*

Research question 5.4: What are ideal pressure patterns for basic skiing styles?

The pressure patterns were calculated, as outlined in chapter 5.5.2, from the professional skiers' sole pressure distribution data and cover the basic characteristics of skiing technique that were previously discussed (ventral-dorsal ratio, outer versus inner ski loading and outer versus inner ski edging). The results for the carving skiing style of medium long turns are presented here. The outcomes serve as the database for the development of the initial training algorithm which is presented below in the design of the training feedback system section. Defining the neutral position is an important prerequisite for collecting measurements in ski loading by means of sole pressure distribution. In this work, the neutral position is defined as the equilibrium of loads on two opposed clusters. For example, the ventral-dorsal neutral position of the outer ski is indicated as follows (see Figure 5-11, left, for the cluster syntax).

$$Q_{vd\text{-}out} = (S_{vm\text{-}out} + S_{vl\text{-}out}) / (S_{dm\text{-}out} + S_{dl\text{-}out}) = 0 \qquad (5\text{-}5)$$

On a logarithmic scale, values greater than zero represent a ventral shift and values less than zero represent a dorsal shift (Figure 5-17). A review of the ventral-dorsal ratios showed that turns are introduced by a ventral shift of load on the outer ski (Figure 5-17, top). As the skier approaches the steering phase of the turn, the loads on inner and outer ski converge towards the neutral position, or zero, before they increase again as the skier approaches the change of turn. The outer versus inner ski loading ratio is characterized by a pyramid shape. It is possible that the ratio approaches zero during the change of turn when skiing direction is changed and a load shift occurs between the outer and inner ski (Figure 5-17, middle).

In the illustration of edging (Figure 5-17, bottom), the convention is that the medial edge is the inner edge of the ski and the lateral edge is the outer edge regardless of whether the ski is the outer or inner ski. The edging ratios for the outer and inner ski converge to zero around the change of turn, which is reasonable because the edging direction changes when the skier is changing direction. The outer ski sees increased edging at turn introduction (to accomplish the change of direction). It increases to more edging in the steering phase and remains on this level until the change of turn. The inner ski's edging ratio reaches a maximum during the steering phase and decreases near the change of turn. The mean values of the different characteristics are summarized in Table 5-7.

*Table 5-7: Mean values for professional skiers' characteristics of skiing technique in the skiing style carving. The parameters represent the mean of the respective ratios Q*

| *Parameter* | *Mean outer ski (dB)* | *Mean inner ski (dB)* | *Mean overall (dB)* | *Mean SD (dB)** |
|---|---|---|---|---|
| Ventral/dorsal shift ratio | 1.00 | 0.59 | 0.80 | 0.73 |
| Outer-inner ski loading ratio | | | 0.36 | 0.35 |
| Medial/lateral edging ratio | -0.28 | 0.05 | 0.33 * | 0.11 |

* Absolute value

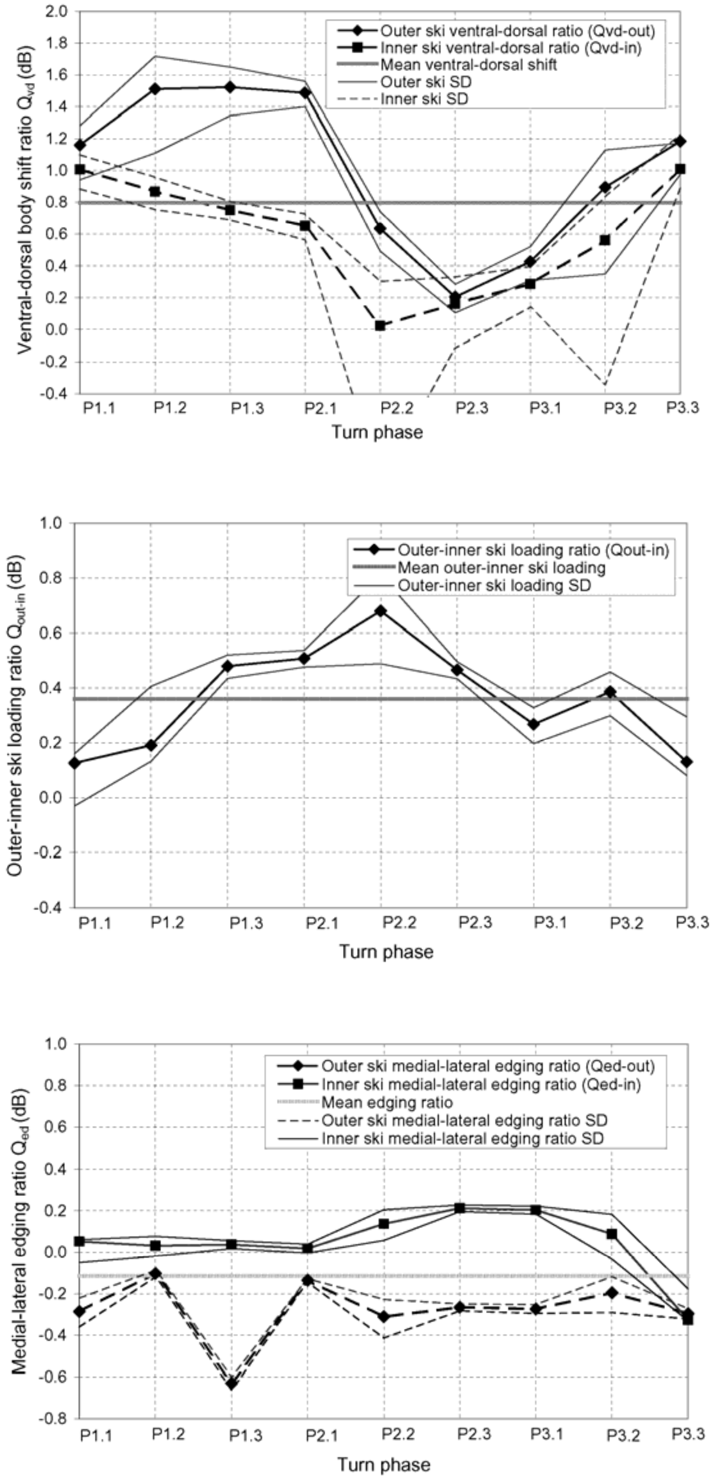



*Figure 5-17: The reference data was calculated from 26 carved ski turns, performed by three different professional skiers. The ventral-dorsal ratio is a measure for the forward and backward shift of the skiers body's center of gravity, the outer-inner ski loading ratio indicates the lateral load distribution between the left and right ski and finally, the edging ratio indicates how much load is put on the medial or lateral edges in a ski turn.*

## 5.6 Sports technology design: Functionality and prototyping

After the general feasibility of the sole pressure distribution for analyzing basic characteristics of skiing was verified, prototypes of an audio feedback training system were designed. Although the prototypes were not designed to fulfill all requirements necessary for introduction to the consumer market, they did incorporate the core functionality. The prototypes served to clarify the following research question:

6. Is it possible to design a mechatronic system which measures the sole pressure distribution, is easy to handle and capable of producing the pressure data in real-time?

As presented in the subsequent chapter, the prototypes would be further used to evaluate the effect of audio training feedback and its general applicability in skiing. This led to the second research question:

7. Is it possible to develop and implement an algorithm which is capable of analyzing, interpreting and reproducing the provided data in real-time?

The following sections provide a brief overview of the system design. The complete design process, however, required profound engineering in insole mechanics, sensors, electronics, radio transmission and software design which is not presented in detail in this thesis.

### 5.6.1 Hardware design of the prototype system

The hardware system for the Digital Skiing Coach should incorporate all elements necessary for sole pressure measurement, data processing and data transmission in an easy to use and cost efficient package. The 99 sensors of the Novel Pedar-X® system used for the feasibility study cover the entire sole area and therefore assure optimal correlation between the actual sole pressure distribution and the acquired sensor data. The system, however, was designed for scientific research and training analysis in professional sports. It sells for approximately 25.000 €, requires careful handling by specialists and does not provide any real-time feedback. Further, the sensor insoles are connected to the data acquisition box via a cable, which is very sensitive and fault-prone because of lead fractures and defective cable connection. In other words, the system is not suitable for a standalone application in leisure sports. The system presented here was developed for use in leisure sports, which at the same time must comply with the requirements identified in the surveys presented in chapter 3. Currently, there is no such system on the market.

Clarification of functionality: With respect to functionality, the research questions regarding the hardware design must be extended to the following topics:

- Full integration and handling: The most prominent prerequisite for the application of mechatronic systems in leisure sports is the ease of use. Therefore, the sensor insole needs to be fully integrated. External parts, cables and switches would be prone to damage from harsh environmental conditions and hamper intuitive handling. To meet the prerequisite, a radio module for data transmission would be required. In spite of these requirements, the insole must be fully flexible to maintain its wearability.

- Low power electronics and data transmission: In addition to being fully integrated, the design must also consider the requirement for a low power system. A daily change of batteries would not be acceptable to users. Further, a modern-day system design must also take into account ecological compatibility.
- Real-time capability: The present system is designed for use as training support during sports activity. As discussed above, knowledge of performance feedback in real-time is the most suitable technique for obtaining improvements in motor learning.
- Low cost design and reliability: Some mechatronic systems on the market have good functionality but elevated retail prices or poor durability. To reach volume markets, it is essential to incorporate low cost parts and robustness in a high quality package.

Figure 5-18 shows the final functional structure of the sensor insole that served as a basis for the prototype design and later the embodiment design. The structure contains all basic functions of the system as well as the corresponding requirements. To facilitate implementation, components of the prototype were clustered into design modules (e.g. power management or radio transmission).

Prototyping: During design of the prototype, focus was placed on the functionality of the sensors, radio transmission and power supply. Because of the high mechanical efforts of a full integration, the electronics were placed in small boxes (function: protection of electronics) which could be switched on or off manually (function on/off, see Figure 5-18). The boxes were then connected to the insoles via cables and were strapped to the leg of the skiers. This design was sufficient for the prototype because the prototype systems were only used for the evaluation study under the supervision of specialists. The sensor insoles were constructed using insoles available for orthotic purposes that were then covered with a 3.0 mm rubber foam material (function: load transmission).

With respect to the pressure sensors, circular resistive foil sensors (FlexiForce, TekScan® Inc., function: pressure sensing), which covered the necessary load range (up to ~ 0.8 N/mm²), were used for the prototypes. These sensors can be run by simple operational amplifier circuits. In contrast to the results of the feasibility study, the sensor insoles were equipped with three instead of four pressure sensors (two at the forefoot and one at the heel, see Figure 5-18) because the evaluation study only considered ventral-dorsal shifts, not edging. The heel sensor was twice as the size of the forefoot sensor to equalize sensor area.

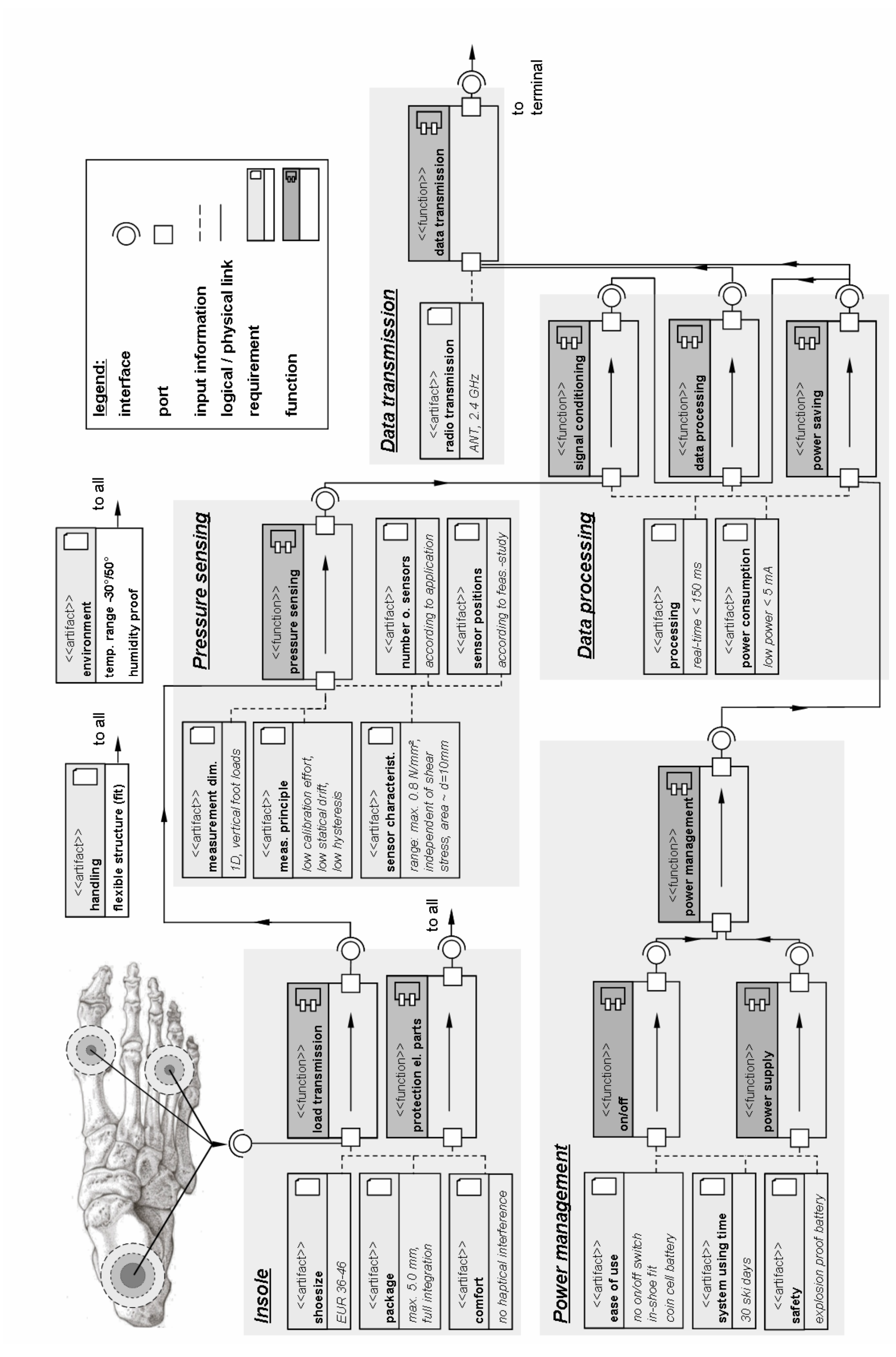



*Figure 5-18: Functional structure of the sensor insole. The figure depicts the main functions, corresponding requirements and the interconnections.*

The loading characteristics of the sensors were determined by subjecting them to calibration routines on a testing machine. The non-linear elements in the sensor characteristics were compensated for during the post-processing routines embedded into the signal conditioning function of the electronics system. In addition, this function includes the analog-to-digital conversion of the sensor data and basic averaging algorithms. This, along with the data processing, was carried out on a microcontroller. The microcontroller also incorporated the coding (data compression) and packaging of the data and the interface to the radio module. The design of power saving algorithms were not included in the prototype but were addressed in the embodiment design as discussed in subsequent chapters. A smart enabling of the feedback algorithm was activated by an acceleration sensor used to indicate if the skier was moving or standing still, such that audio feedback was only provided while the skier was in motion (see section training algorithm below for description). The neutral ventral-dorsal sensor characteristics of the insoles were determined by loading the soles with the neutral foot positions of different subjects on a setup with two wages at the front and the back of the setup. Thus, it was possible to validate the correlation coefficient between the subject's balance and the corresponding sensor values. Data transmission was achieved with a radio module whose core technology should also be implemented in the final design. The transmission is based on a digital radio protocol on the 2.4 GHz band (protocol stack: ANT, see http://www.thisisant.com for further information) which allows low power applications of data transfer rates up to 116 kilobits per second (similar to transmission rates by Bluetooth). In addition, the power management was designed with respect to later embodiment. A low dropout regulator type Linear LTC3009 was used to regulate the system voltage at a stabilized 3.0 Volts. The power supply was composed of a common coin cell type CR2032 that is also used in sport watches and heart rate monitors.

A small handheld computer (PDA) operating Windows CE 5.0 was equipped with mini SD radio cards to receive the sensor data from the insoles. The feedback software was implemented in C-Sharp (see Zierer, 2008, for a comprehensive overview about the software design). Its functionality will be outlined in the following section. As for the audio feedback, a small headphone was plugged to the PDA.

Verification of real-time feedback: Because the entire feedback concept relies on immediate feedback about motor activity, one of the main goals for the prototype systems was to ensure real-time capability. The overall delay periods were evaluated in terms of producing data sets of a known time pattern on the insoles and displaying a corresponding audio feedback on an oscilloscope. A microphone was coupled to the oscilloscope which collected the audio signals from the speakers (see Czabke, 2008 for a description of the setup). For the setup presented here, the delay times averaged from 80 ms to 200 ms, which is considered an appropriate delay period for real-time perception of athletes during sport in the literature (see chapter 5.3.2).

Figure 5-19 depicts all components of the prototype system.

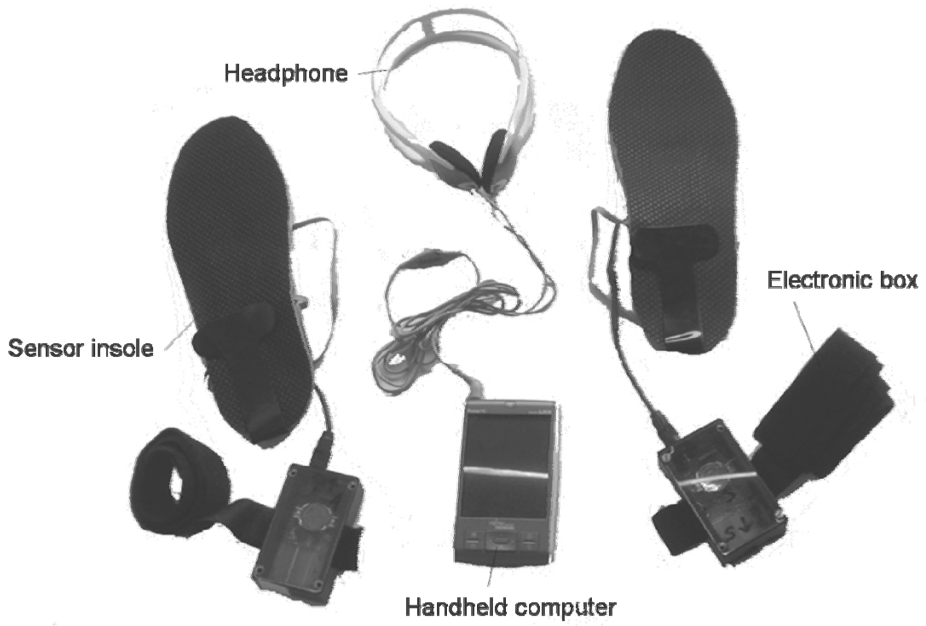



*Figure 5-19: Components of the prototype system of the Digital Skiing Coach.*

### 5.6.2 Training feedback algorithm

The software design, specifically the training feedback algorithm, were used as a stand-alone application on the handheld computer. The software incorporated a hardware interface module with the ability to facilitate communication with the radio protocol and data conditioning (e.g. decoding of sensor data), a processing module which carries out the training feedback algorithm and a graphical user interface (GUI) which facilitates different controls (e.g. calibration, start, stop, data logging). Two important parts of the prototype software will be outlined in the following.

Feedback generation: After testing a variety of different types of audio feedback, it was determined that spoken advice is not suitable for receiving feedback because of the high mental effort required for translating the information into appropriate motor activity (see also Effenberg, 1996; Effenberg, 2000, pp. 19ff). Instead, beep tones with a constant modulation were found to be effective. The tones varied in frequency according to the level of fulfillment of the motion task. The audio feedback which based on the ventral-dorsal body shift of the skier was referenced to static loading limits in the prototypes. As soon as the ventral-dorsal ratio of the skier fell below the static level previously measured, a "beeping" signal was triggered (Figure 5-8). The limit corresponds to an index which is calculated from the reference data of professional skiers and the motor abilities of the actual user as established in a calibration run. Two additional levels of beeping frequency were implemented to account for different characteristics of the ventral-dorsal ratio. The intensity of the audio feedback, i.e. the frequency of beeping, increased with a decreasing ventral-dorsal ratio (see also Figure 5-8, below). Based on findings in test runs, a delay was implemented to suppress audio feedback because of small fluctuations about the reference line which tended to irritate the skiers.

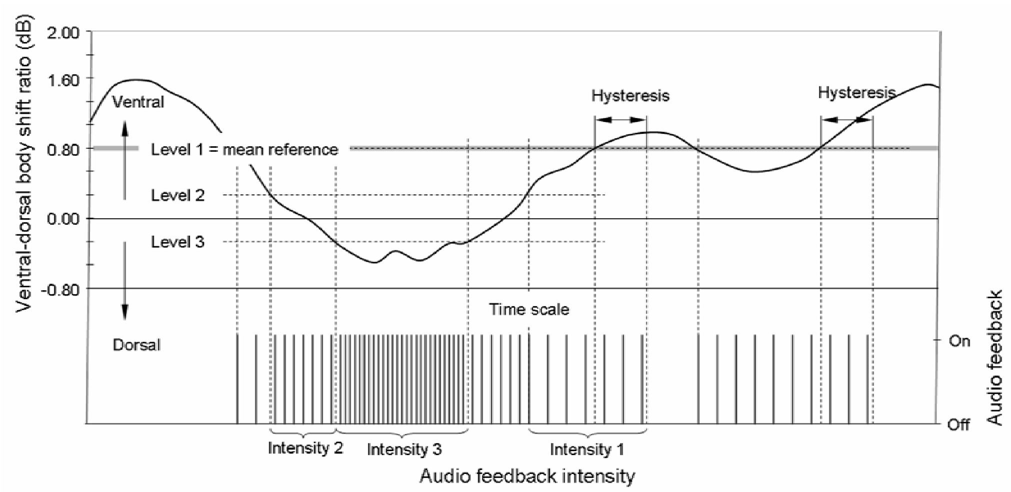



*Table 5-8: Audio feedback generation with respect to the ventral-dorsal body shift ratio. Three levels of "beeping" audio feedback with increasing beep frequency from level 1 to level 3, corresponding to decreasing ventral-dorsal ratio, were implemented. A hysteresis avoids nervous swapping of the feedback around the reference line.*

Smart enabling of algorithm: The acceleration sensor used to indicate skiing activity was incorporated into the embedded system. The sensor was later used to also identify pattern recognition. For example, it is obvious that audio feedback is not necessary or useful when skiers ride uphill in the ski-lift. Therefore, the training feedback algorithm was activated by an activation index calculated from the pressure sensors and the acceleration sensor.

### 5.6.3 Summary

During development of the prototype sensor insole, the system was complemented with audio training feedback functionality to evaluate the training effect of real-time audio feedback. Major design tasks regarding the system functionality were addressed, implemented and tested including, a sensor insole, an embedded system incorporating power management, data processing, radio transmission and corresponding embedded and training software which was implemented on a handheld computer. The prototype system lacks several basic usability characteristics: a specialist is needed to operate the hardware and the software;

pattern recognition and power saving algorithms were not implemented; and the systems were not built into a fully integrated sensor insole package. These aspects will be implemented in the final design. The following evaluation study should further deliver detailed input for the final design.

## 5.7 Effect of feedback training and evaluation of fun experience in skiing

Basic principles and the clarification of important prerequisites with respect to a training feedback system for leisure skiing have been presented above. In addition, a brief overview of the system design illustrated the impact and implementation of these prerequisites in the design of mechatronic sports technology. The present chapter is dedicated to verifying the effects of the training feedback system as related to skiers' learning ability and emotional experiences. The two main research questions formulated in the introductory section shall be verified:

1. Is the Digital Skiing Coach a suitable system to enhance fun experience?
2. Is it possible to enhance skiing technique using the Digital Skiing Coach?

The chapter begins with the introduction of several considerations about the validity of learning studies. Valid causal interpretations of learning processes are generally difficult to identify because the learning effects are subject to a variety of confounding factors. For instance, the results of a pre-test/post-test experiment in sport are influenced by the daily lifestyle habits of the subjects. What do they eat? Are they living on the 1$^{st}$ or the 5$^{th}$ floor, with or without an elevator? Do they cycle to work or go by bus? Obviously these influences have even greater impact when the actual effect of the training treatment is small. Hence, validating retention is difficult. A second problem is that an individual can only be tested once on a certain motor skill or performance level. As soon as a treatment occurs, the quality criteria may be biased. In addition, a setup with two groups, an experimental group subjected to an experimental and a control group, bears systematic deficiencies: statistics aim to generalize effects observed in the experimental group by comparing it to the control group. But different subjects implicitly have different learning habits and skills.

In this sense, a study design is always a trade-off. In the present study, influencing factors were controlled by narrowing the time frame and by standardizing the test environment. The results of the study are presented in the following sections.

### 5.7.1 Approach and research questions

The approach for the present study is based on the previously produced prototypes and established research questions. For the field experiment, a questionnaire was developed to evaluate subjective sensations experienced during the experiment. After data analysis, the general applicability of the training system could be verified

(Müller, 2009). The results provided input for iterations in system design and other design factors associated with market development (Figure 5-20).

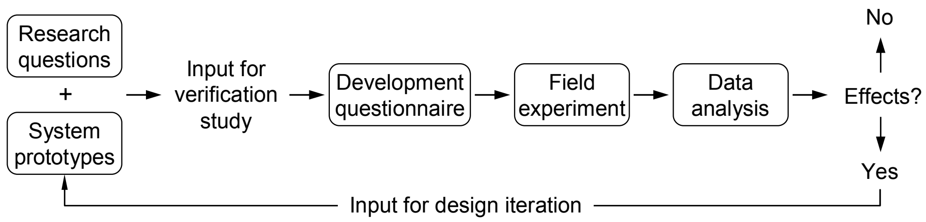



*Figure 5-20: Approach for the present study.*

With respect to design operationalization, the main research questions were as follows:

1.1 Is the interaction with the Digital Skiing Coach fun?
Positive emotions can be promoted by the interaction with the feedback system, in addition to the training effects and resulting enhancement in skiing technique.

1.2 Can a more intense sensation of fun experience because of dynamic acceleration in ski turns be achieved with the use of the Digital Skiing Coach?
One goal of the Digital Skiing Coach is too facilitate better ski turns and skiing technique. Beginners typical ski very slowly through ski turns. The question is if the improved skiing technique in turns, and the resulting increase of acceleration, generates a more enjoyable experience. The answer to this question is dependent on question 2.1.

2.1 Does the Digital Skiing Coach cause skiers to perform a ventral shift in turns?
An important characteristic of ski turns is achieving the proper ventral shift of the body. This results in better ski control and safer and more dynamic skiing. The goal was to evaluate objectively if the audio training feedback system helps improve this basic characteristic better than conventional instructions.

2.2 Do skiers subjectively have an improved sense of motion characteristics?
In addition to objectively evaluating the training effects of the Digital Skiing Coach, it is important to also include the skier's perception of the training..

2.3 Do skiers find the Digital Skiing Coach irritating?
Audio feedback during skiing may interfere with the concentration of the skier. With respect to system design and safety considerations, it is important to evaluate whether skiers feel the device interrupts their attention.

### 5.7.2 Study design, materials and methods

Study design:

The study was designed as a comparative longitudinal field experiment consisting of a pre-test and post-test. Two sample groups completed test cycles in skiing on a course with 20 predefined turns with free skiing between the turns. The experimental group was equipped with the Digital Skiing Coach which incorporated real-time audio feedback relating to the ventral-dorsal (forward-backward) body position (dependent variable). The pressure measurement insoles were placed in the ski boots and earphones were used to provide the audio feedback generated by the handheld computer. The control group did not receive any feedback during skiing. Both groups were beginner to intermediate skiers. The skiers were provided with written and visual instructions prior to each test cycle of the technique exercises to be accomplished in the ski run. The sole pressure distribution of both groups was collected for all test cycles. The objective skiing skills were evaluated by comparing the sole pressure distribution (dependent variable) from two preliminary test cycles with the two post-test cycles. The post-test was completed on courses with different turn characteristics (course A and course B in Figure 5-21, right). Between the pre-test and the post-test, both groups performed eight training runs on a free slope.

| | No. | Slope type | Purpose | Advice * | Feedback** |
|---|---|---|---|---|---|
| | 0 | free slope | warm-up | | |
| Pre-test | 1 | parcours A | pre-test | | |
| | 2 | parcours B | pre-test | | |
| Training-phase 1 | 3 | free slope | training | x | x |
| | 4 | free slope | training | x | x |
| | 5 | free slope | training | x | x |
| | 6 | free slope | training | x | x |
| | | | pause 45 min. | | |
| Training-phase 2 | 7 | free slope | training | x | x |
| | 8 | free slope | training | x | x |
| | 9 | free slope | training | x | x |
| | 10 | free slope | training | x | x |
| Post-test | 11 | parcours A | post-test | | x |
| | 12 | parcours B | post-test | | x |

* All subjects received written and visualized advice about technique training
** Only the experimental group was subject to audio-feedback during skiing

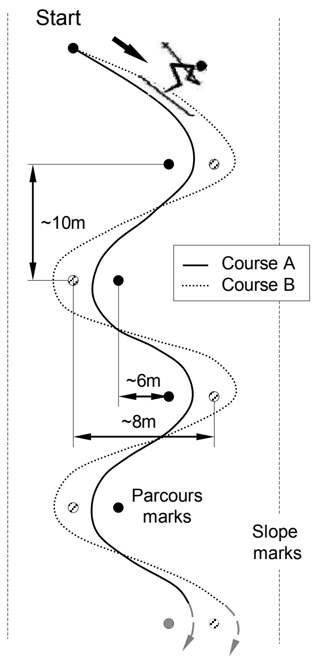



*Figure 5-21: Test plan of the study (left): The experiment included 13 runs for each subject. Between the pre-test and the post-test, all subjects completed training runs on a free slope. Before the training runs, each subject was given both written and visual instructions for technique training. In addition, the experimental group was subjected to audio feedback during skiing. The pre- and post-tests were conducted on a predefined course that was prepared on a marked slope (right).*

The test plan and outline of the predefined course are depicted in Figure 5-21. With the exception of test-cycle seven, the motion task goal was to perform a ventral-dorsal shift towards the turn introduction. Based on the system design, the audio feedback provided to the experimental group should indicate the heel kick that occurs before the turn introduction. In test cycle seven, an additional motion task goal was provided. The subjects were asked to try and load the outer ski as much as possible while maintaining the ventral-dorsal shift.

In contrast to a conventional pre-test/post test experiment, the experimental group was subjected to treatment (audio feedback) during both the pre-test and the post-test. Because retention effects were not the focus of the study, this approach was regarded as an appropriate way to increase the probability of the primary effect (difference between the training methods). After the subjects completed all test cycles, their experiences and emotions during the experiment were evaluated through a questionnaire. The basic parameters of the study and the working hypotheses are summarized in Table 5-9.

Control of confounding factors:

Precautions were taken to reduce the influence of confounding factors on the results

*Table 5-9: Basic parameters of the study*

| *Parameter* | *Specification* |
|---|---|
| Statements<br>(working hypotheses) | 1. Acousting training feedback leads to an improvement regarding the forward to backward balance of beginner/medium-skilled skiers during skiing.<br>2. After training with audio feedback, the skiers subjective impression regarding their skiing skills has improved.<br>3. While/after training with audio feedback, the skiers sense a more intense feeling of fun in skiing. |
| Skiing style | - Skidding middle turn (turns on medium steep slope 10° – 15.5°, radius ~6m) |
| Skis<br>Ski boots<br>Binding and plates | - Völkl Unlimited TOS, radius 12m – 18m<br>- Technica Entryx RT<br>- Marker Rental |
| Location and date | Ski-hall, Bottrop, Germany<br>Dec. 8th 2008 to Dec. 12th 2008 |
| Testing slope | length l = 200m, width w = 20m (marked off)<br>number of gates k = 20<br>distance between gates j = 10m<br>width of gates w = 6m and 8m (2 variants) |
| Conditions | Snow: artificial, granular<br>Temperature: -4°C to 0°C |

of the study. First, the study was conducted on an indoor ski hill, which eliminates the influence of different weather and snow conditions. Throughout the study, the snow conditions remained relatively stable (see Table 5-9). Second, a predefined course was chosen to facilitate standardized test conditions for both the pre- and post-test (Figure 5-21, right). It is expected that a prepared course is more difficult for beginner and intermediate skiers to master than an open slope. However, this setup was necessary to establish standardization. Third, each subject performed all test cycles and training runs in a single day. By completing the tests in a single day, biasing from everyday living habits should be avoided in contrast to experiments in which the pre- and post-tests are conducted on different days. All subjects had completed a basic skiing course before and had not skied since the previous ski season, indoors or outdoors. To avoid having the experimental group and control group influencing each other by conversation, half-day sessions were scheduled in alternating order, i.e. each day was divided into testing three subjects of the experimental group and three subjects of the control group. The order was changed randomly. In addition, it is possible that the efficiency of an audio feedback system might be influenced by the subject's skiing skills. Therefore, the subjects were selected by classifying them according to their skiing skills which were evaluated by an internationally accepted rating scale (DIN ISO 11088). Moreover, the written and visual instructions presented to the subjects to clarify the training tasks were standardized, i.e. no additional information was provided orally (see Figure 5-22).

Finally, the use of an audio feedback system itself might have caused interruptions in the subject's concentration. To understand this, one has to keep in mind that skiing is a very challenging sport in terms of the motion tasks. Beginners and intermediate

*Figure 5-22: Exemplary visualization as it was presented to the subjects as instruction for the purpose of the training runs.*

skiers have to concentrate fairly hard to master the techniques of skiing. Additional information from an audio feedback system might over task perception abilities and impede concentration. This effect could not be evaluated systematically, however, the questionnaire included content aimed at identifying if the subjects felt disturbed or inhibited by the audio feedback.

Sample group:

The sample group was recruited by announcing the study on different information channels at the universities in Bochum and Cologne, on the website of the indoor ski-hall and via e-mail to ski schools. Thirty-four skiers responded to the announcements, and 24 subjects were selected by classifying their skiing skills according to parameters provided in DIN ISO 11088 as evaluated through the prepared questionnaire. In addition, a sports activity index was calculated from questions about general sports activity and number of skiing days per year. The rating scale included three levels ("very active" = 3, "active" = 2, "low activity" = 1). The index was calculated in terms of a weighed mean value. The subjects selected for the sample group were found to be moderately active. The characteristics of the sample group are depicted in Table 5-10.

*Table 5-10: Characteristics of the sample group. The scale of the sports activity index ranges from 1 (low activity) to 3 (very active)*

| *Sample group parameter* | *Specification* | |
|---|---|---|
| Size | N = 34 | |
| Participants | n = 24 (selection regarding skiing skills) | |
| Skiing skills | Beginner/medium-skilled (selection according to DIN ISO 11088, evaluated by questionnaire) | |
| | *Experimental group* | *Control group* |
| Age | $\bar{x}$ = 30.0 y (SD = 8.7) | $\bar{x}$ = 28.6 y (SD = 10.2) |
| Gender | f = 50 %, m = 50 % | f = 50 %, m = 50 % |
| Sports activity index | **A** = 1.68 | **A** = 1.82 |
| Sports activity level | medium | medium |

Half a day was designated for each subject to accomplish the test cycles and the training runs as described above.

The sport (skiing) motives of the sample group were evaluated to verify whether their motivation for skiing is similar to the sample group that participated in the survey conducted in chapter 3.3. Table 5-14 depicts the ranking of sport motives by the subjects in this study and the results correspond well, with the exception of thrill which was rated higher by the athlete's in chapter 3.3, to the ranking of motives reported by athletes as discussed in chapter 3.3. Fun experience was rated as the most important motive for leisure skiing by both groups surveyed.

Methods and tools: The Digital Skiing Coach prototypes were used to collect the sole pressure distribution and generate the audio training feedback during skiing (see section 5.6). In addition, all ski runs were video-taped to facilitate turn detection for data analysis. As mentioned above, written and visual instructions were used to explain the training purpose in a standardized way. In addition, a questionnaire was developed and categorized as follows:

1. Questions about fun experience and emotional state.
2. Questions about the sensation of motion because of audio training feedback (only for experimental group).
3. Questions about sports activity, sport motives and motives for skiing.
4. Questions about disturbing influences because of audio training feedback or the test setup.

*Table 5-11: Sample group's sport motives. The ranking corresponds to the outcomes of the athlete survey presented in chapter 3.3. The variance of the standard deviation between the two sample groups was very low, i.e. both sample groups shared similar sport motives*

| *Sport motives* | *Statistics (n=24)* | |
|---|---|---|
| | *1 Rating scale 4* | *1 = low, 4 = high* |
| Fun experience | | $\bar{x}$ = 3.4 (SD = 0.8) |
| Health | | $\bar{x}$ = 2.6 (SD = 0.9) |
| Wellbeing | | $\bar{x}$ = 3.4 (SD = 0.7) |
| Achievement | | $\bar{x}$ = 3.1 (SD = 0.9) |
| Thrill | | $\bar{x}$ = 2.0 (SD = 0.9) |
| Socializing | | $\bar{x}$ = 2.5 (SD = 1.1) |
| | Max. variance of SD between sample groups: $\Delta_{SD,max}$ = 0.3 | |

As for the question categories one and three, the questions were taken from the questionnaire developed for the quantification of fun (see chapter 4.4). Some of the questions had to accurately represent skiing. Question categories two and four were newly developed. The questionnaire was comprised mainly of closed questions with respect to data analysis. The rating scale for the closed questions was a four-step ordinal scale with the following response categories: "fully applies", "mainly applies", "partly applies" and "does not apply". The response categories were given corresponding numbers (fully applies = 4, does not apply = 1). Several examples of the questions formulated for the newly developed question categories are as follows:

2. – Did you have the impression that the Digital Skiing Coach helps you in teaching the sensation of motion?
   – Do you feel that you could interpret the feedback that was provided by the Digital Skiing Coach?
4. – Did you feel that the Digital Skiing Coach was disturbing you?
   – Did you feel that the Digital Skiing Coach was distracting you?

The complete questionnaire can be found in the Appendix 8.4.2.

### 5.7.3 Execution and data analysis

Execution of the experiments: Before the test cycles, each subject was equipped with appropriate ski equipment and the Digital Skiing Coach system. The experimental group wore yellow shirts and the control group wore red shirts to allow for identification in the video analysis. After a warm-up run, the two test cycles of the pre-test were conducted on the prepared slope, followed by four training runs on the open slope. To synchronize the video data and the sole pressure data, a small jump was performed prior to beginning a run. Video data was required to verify the sole pressure data of individual turns used for later statistical generation. After a break of 45 minutes, the subjects performed four additional training runs on the open slope, followed by two test cycles (the post-test) on the prepared slope. The first run of each pre- and post-test cycle was performed on the narrower course (course A) of the prepared slope and the second run was completed on the wider course (course B). After the experiment, the subjects completed the questionnaire individually.

To verify the effects of the Digital Skiing Coach on the motor learning process, two calculations were conducted to calculate descriptive statistics.

Macrocosm – mean overall ventral-dorsal ratios: First the macrocosm, or averaged ventral-dorsal ratio over the entire treatment, of the outcomes is presented. This refers to the learning effect over the course of the consecutive phases (from pre-test to post-test, and between two training phases) of the experiment. The averaged ventral-dorsal ratio aims to clarify whether the subjects improved their overall body balance from the pre-test to the post-test. The quality criterion for assessment is the average ventral-dorsal (forward-backward) body balance. For the descriptive statistics, cumulated mean values of ventral-dorsal ratios (summation of both feet, respectively) of the two pre-test cycles, $Q_{vd,pre\text{-}test}$, compared to the ratios of the two post-test cycles, $Q_{vd,post\text{-}test}$, for experimental group and control group were calculated (according to the approach which was chosen in the feasibility study). These values provided simple quality indicators before and after training. Additionally, the results of each of the 12 test cycles were calculated in the same manner to examine how the quality criterion progressed from test cycle to test cycle.

In terms of inferential statistics, it was verified if the experimental group and the control group developed their skiing skills significantly comparing the pre-test and the post-test results of each group. For data analysis, experimental and control group were parallelized ex post in terms of building blocks concerning an individual pre-test attribute. The attribute based on the static calibration value that was determined in a standing position beforehand the test runs and the vetral-dorsal body shift ratios that were collected during the pre-test runs of the experiment. This ratio in general provides a good objective indicator of the skiing skills and hence can be used for parallelization as well. The results of the block building are depicted in Table 5-12.

*Table 5-12: Results of the block building – the ventral-dorsal body shift ratio is an objective indicator for skiing skills and hence can be taken for ex post categorization of the sample group*

| *Block-no.* | *Mean ventral-dorsal shift experimental group ** | *Mean ventral-dorsal shift control group ** |
|---|---|---|
| 1 | -0.24 | -0.20 |
| 2 | -0.21 | -0.12 |
| 3 | -0.05 | -0.01 |
| 4 | 0.19 | 0.05 |
| 5 | 0.22 | 0.10 |
| 6 | 0.27 | 0.12 |
| 7 | 0.28 | 0.13 |
| 8 | 0.31 | 0.14 |
| 9 | 0.33 | 0.14 |
| 10 | 0.37 | 0.39 |
| 11 | 0.64 | 0.57 |
| 12 | 0.72 | 0.94 |
| **Mean** | **0.24** | **0.19** |

* Mean values were calculated from pre-test runs 1 and 2 by relating the loading on the ventral sensors to the loading on the dorsal sensor

According to the results of a Kolmogorov-Smirnov test, the pre-test attributes follow a Gaussian distribution. A t-test was calculated to check if the mean values of the pre-test attributes varied significantly. For $\alpha = .05$, experimental group and control group do not vary significantly concerning the pre-test attribute. This means that both groups displayed similar skiing skills in the pre-test runs (Table 5-13).

Further, it was verified if the two subject groups displayed significantly different

*Table 5-13: Results of the t-test which was calculated to verify if experimental group and control group had similar skiing skills at the beginning of the experiment*

| *Subject group* | *Pre-test attribute** | *Test statistic t* | *Df* | *Significance p (bivariate)* |
|---|---|---|---|---|
| Control group | .19 | .75 | 9 | .472 |
| Experimental group | .24 | | | |

* The pre-test attribute here is the overall mean of the mean ventral-dorsal body shift ratio of all subjects of the experimental group and the control group, respectively

skiing skills by the end of the experiment (which was checked in terms of a t-test as well).

Microcosm – ventral-dorsal shift with respect to single turns: Second the microcosm of a single ski turn was considered. This analysis aimed to verify how subjects developed the motor ability[8] to vary their body balance during the course of a ski turn according to the applied training method. As seen in chapter 5.4, the variation of the body balance is the core element of a proper ski turn. For this analysis, the test cycles of all subjects of the experimental and control groups were segmented into single turns by matching the video and sensor insole data and normalizing them to a consistent duration (i.e. the data set corresponding to a single turn was stretched by interpolation or compressed by averaging so that 1000 equally spaced data points covered the turn duration). Mean values were calculated for each individual turn with respect to the turn phases. Because the levels of the ventral-dorsal ratios varied between subjects, the data for each turn was reprocessed by subtracting the subject's mean value. This reprocessing ensured that all data sets were represented relative to a neutral "zero level". This method allowed for a qualitative comparison between the different phases of the experiment as well as for a comparison between the two sample groups.

Figure 5-23 illustrates how the data was processed with respect to these two viewpoints.

**Macrocosm (pre-test):**
Ventral-dorsal ratio above all subjects and with respect to the pre-test (test cycles 1 and 2)

With x(n) see below

$$Q_{vd,pre-test} = \frac{\sum_{n=1}^{1000} x(n)}{n}$$

**Microcosm (pre-test):**
Data point n above all subjects and with respect to the pre-test (test cycles 1 and 2)

With n = [1,1000] Є (IN)
j = [1,2] Є (IN)

$$x(n) = \frac{\sum_{k=1}^{20} \left( \frac{\sum_{j=1}^{2} \left( \sum_{i=1}^{12} x_i(n)/12 \right)_j}{j} \right)_k}{k}$$

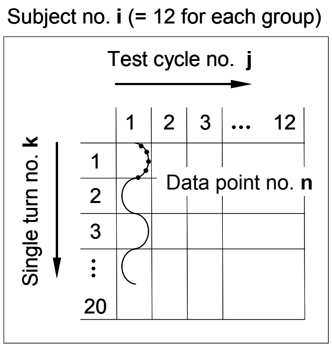



*Figure 5-23: Example calculation for the pre-test phase. The other phases (trainings phases 1 and 2, post-test) were calculated accordingly.*

[8] The term "motor ability" is used here because the time scale of the experiment was short such that sustainable retention effects which indicate a transfer to "motor skills" are not expected

Figure 5-24 depicts the “zeroing” of the raw sensor data which served to average the data over all subjects in a sample group. In order obtain a measure to compare the effects of the audio training feedback to motor activity, the data was further clustered into three amplitude ranges of the ventral-dorsal body shift (smaller or equal 0.2 dB, between 0.2 dB and 0.4 dB and greater than 0.4 dB). Counting the events in each range (i.e. the number of data samples that represent a ventral-dorsal ratio within one of the three ranges) for each turn phase is an indicator for the ability to shift the body weight ventral or dorsal in a certain turn phase. The sensor setup that was chosen for the present study also appears in Figure 5-24.

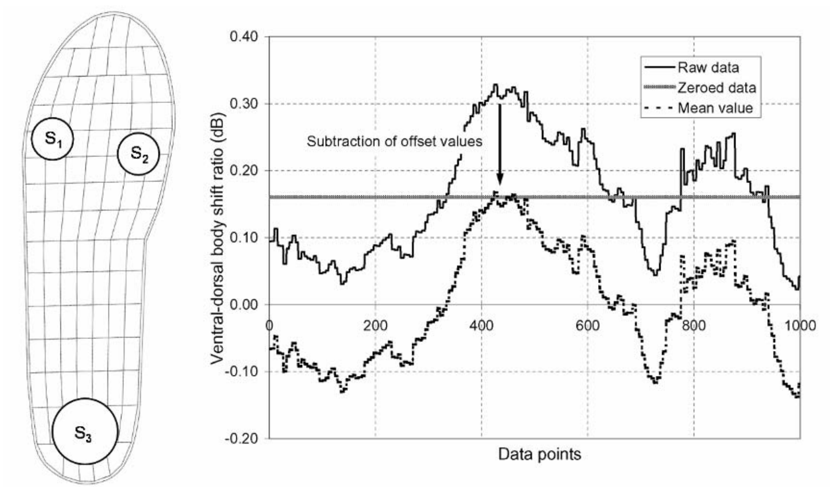



*Figure 5-24: Sensor positions in the study setup and zeroing of raw data for the purpose of qualitative analysis of single turns, averaged over all subjects.*

### 5.7.4 Objective data: Results and discussion

Macrocosm – mean overall ventral-dorsal ratios:

Table 5-14 summarizes the results of the desciptive calculation (mean overall ventral-dorsal ratios). It should be mentioned again that the pre-test and the post-test were performed on a predefined course, while the training phases were performed on an open slope.

It is of interest to note that the average values of the ventral-dorsal ratios for the post-test compared to the pre-test increased slightly (9.1 %) in the experimental group but decreased considerably in the control group (35.1 %), as represented by the Δ values in Table 5-14, and in Figure 5-25. The standard deviations indicate that all stages were accomplished with a relatively constant between-subject variance, with the exception of the experimental group pre-test and control group post-test. Although the test plan incorporated a break in the middle of the experiment, it can be speculated that the relatively high mental stress and challenging motion task led to fatigue by the end of the test cycles. The subjects were all skiers of beginner or intermediate skill level with an average of only a few ski days per year and a moderate level of general sports activity. A full day of intensive skiing was likely too strenuous given their level of fitness.

*Table 5-14: Average values of body balance with respect to the four phases of the experiment and the two sample groups. Additionally, Δ indicates the difference between pre-test and post-test*

| | Experimental group | | Control group | |
|---|---|---|---|---|
| Phase | $\bar{x}$ | SD | $\bar{x}$ | SD |
| Pre | 0.60 | 0.28 | 0.57 | 0.22 |
| T1 | 0.64 | 0.18 | 0.47 | 0.18 |
| T2 | 0.61 | 0.17 | 0.43 | 0.21 |
| Post | 0.66 | 0.20 | 0.37 | 0.13 |
| | $\Delta = (\bar{x}_{post} - \bar{x}_{pre})$ | | $\Delta = (\bar{x}_{pre} - \bar{x}_{post})$ | |
| | 0.06 | | -0.20 | |

While the two sample groups started with an almost equal level of the ventral-dorsal ratio, the characteristic development during the experiment changed. In particular, two findings bear further discussion. The experimental group increased its performance (forward-shift during the ski turn) from the pre-test to the first training phase by 6.3 % while the control group decreased by 17.5 %, which is a delta of 23.8 %. Because the starting level was nearly equal, it seems obvious that the experimental group was able to respond to the audio training feedback such that they improved their motor ability better than the control group was able to without feedback. In training phase two, there was a similar decrease in the performance of experimental and control group (0.3 dB and 0.4 dB, respectively), compared to training phase one. The training phases were performed on the free slope instead of the prepared slope used for the test cycles, and were also conducted while other skiers were skiing. This might have negatively influenced the concentration of the subjects. The distraction presented by other skiers may be an important consideration, particularly as skiing lessons are typically taught on open slopes. The results showed that the audio training feedback requires a considerable degree of concentration and care must be taken to ensure the feedback is as intuitive as possible. With extended use, however, it is likely that a familiarization effect will occur. This possibility may be addressed in future studies. The second noteworthy finding occurred between training phase two and the post-test. Between the second training phase and the first post-test, the experimental group's ventral-dorsal body shift ratio improved by 8.2 % while the control group declined by 14.0 %, representing a delta of 22.2 %. It is likely that the effects of fatigue near the end of the experiment were counteracted by the audio training feedback in the experimental group, whereas the control group relapsed to typical insufficiencies of skiing (dorsal shift) without constant feedback.

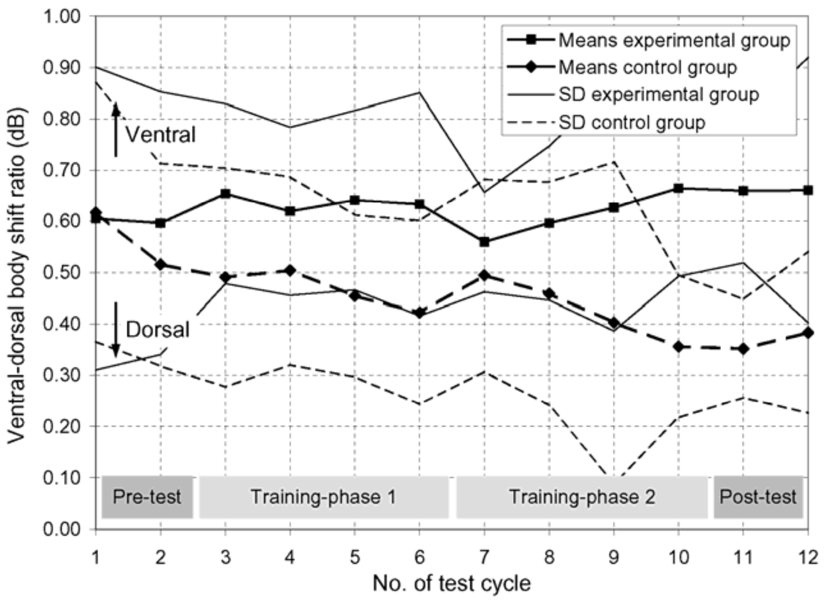



*Figure 5-25: Progress of the average body position of the experimental and control group over all 12 test cycles of the experiment. The curves are drawn with respect to the four phases of the experiment. Values greater than zero indicate a ventral (forward) shift and values smaller than zero indicate a dorsal (backward) shift – with respect to one complete test cycle. The values of the 12 subjects of each sample group were averaged.*

With respect to the single phases, Figure 5-25 illustrates that the slight overall decrease of the experimental group over the training phases is the result of a phenomenon observed in test cycle seven (middle part). The instruction for test cycle seven differed from the instruction for the rest of the test runs. It contained the advice to put as much load as possible on the outer ski while maintaining a decent forward shift of the body's center of gravity during the ski turn. The effect is observed for the control group as well, but with a switched characteristic of the ventral-dorsal ratio. It is interesting that the ventral-dorsal ratio curve exhibited a sharp downward peak at this point while the control group exhibited a sharp upward peak. This effect may have been a product of the test plan because the control and experimental groups were subject to a different instruction/treatment in test cycle 7. Ideally a skier should try to bring as much load as possible on the outer ski in the turns while maintaining an appropriate ventral shift in the turn introduction phase. The complexity of this task may have been sufficient to prevent audio feedback from being processed and transformed into the correct motor activity. The control group, on the other hand, was able to cope with simple verbal instructions. This observation was beneficial in that it led to additional input for improvements of the design: exercises should be kept simple if basic skiing skills are not well-developed. Neglecting these two prominent peaks, the slight upward trend in the experimental group is continuous, as is the downward trend for the control group.

*Table 5-15: Results of the statistical analysis of experimental group and control group concerning the improvements of the quality indicator ventral-dorsal body shift from pre-test to post-test. The experimental group did not improve significantly. The control group degraded significantly*

| *Paired comparison* | | *Statistics experimental group* | | | | | |
|---|---|---|---|---|---|---|---|
| *Factor 1 (I)* | Factor 2 (J) | *Deviation (I-J)* | *Standard deviation* | *Standard error* | *Test statistic t* | *Df* | *Significance (a)* |
| Pre-test | Post-test | .05 | .34 | .11 | -0.479 | 9 | .645 |

| *Paired comparison* | | *Statistics control group* | | | | | |
|---|---|---|---|---|---|---|---|
| *Factor 1 (I)* | Factor 2 (J) | *Deviation (I-J)* | *Standard deviation* | *Standard error* | *Test statistic t* | *Df* | *Significance (a)* |
| Pre-test | Post-test | .24 (*) | .31 | .10 | 3.48 | 9 | .008 |

(*) The deviation is significant on the .05 niveau

Concerning the improvements in skiing skills on the basis of the quality indicator "ventral-dorsal body shift", the experimental group does not improve significantly (see Table 5-15) from the pre-test to the post-test. The quality indicator even decreases significantly for the control group. This means that the decreasing performance of the control group is not random. Finally, the experimental group and the control group vary significantly in the post-test with p = .003

Microcosm – the ventral-dorsal shift with respect to single turns:

The overall ventral-dorsal ratios presented above are valuable in deducing quantitative statements about the general position of the subjects on their skis, but they cannot provide advanced insights into the quality of ventral-dorsal shifts in the course of a turn. We have seen before that the variation of the body's center of mass above the ski is essential for proper turn introduction and ski control. The experimental group was provided both with standardized written and visual instructions before they began the test cycles and with real-time audio training feedback from the Digital Skiing Coach during skiing. In contrast, the control group only received instructions before the test cycles. The results of the second calculation are shown in Figure 5-27. It is interesting to note that the experimental group (left) was able to develop an ability to shift the body weight forward during the turn introduction phase. In the pre-test, both experimental and control groups displayed an unsteady and poor ventral-dorsal shift and no systematic motor activity was observed. The experimental group apparently started trying out to shift their body forward (ventral) in training phase one, but were still not able to uphold the appropriate activities on a constant level for the turn phases to follow, respectively (Figure 5-27, second from the top). Further, in training phase two and the post-test, it is observed that the experimental group performed the dorsal kick which is necessary to bring the body weight forward towards the turn introduction phase (Figure 5-27, bottom and second from the bottom). In the post-test, it appeared the experimental group tried to hold the ventral-dorsal ratio on a constant level during the steering phase. The control group results are inconsistent and show no clear development in terms of a characteristic motion pattern. In both the pre- and post-tests, the control group displayed a noticeable dorsal shift in the turn introduction, which became even more prominent in the post-test. It is possible that the skiers tried to follow the instructions that were provided but were unable to perform them in the correct turn phase because of the complexity of the motion task. This finding, in comparison to observations of the experimental group suggests that the audio training feedback supports motor learning in situations of relatively complex motion tasks.

Finally, Figure 5-26, left, depicts the course and amplitude of the ventral-dorsal body shift during a carved ski turn of professional skiers (data obtained from the study discussed in chapter 5.5), compared to the experimental group's post test results, right. In fact, the large amplitude of the body shift of the experimental group is an indicator that the audio training feedback may be specifically effective in situations were complex motion tasks have to be mastered. The shifting motion, however, still lacks fine tuning and timing. Also, a negative dorsal shift can still be observed.

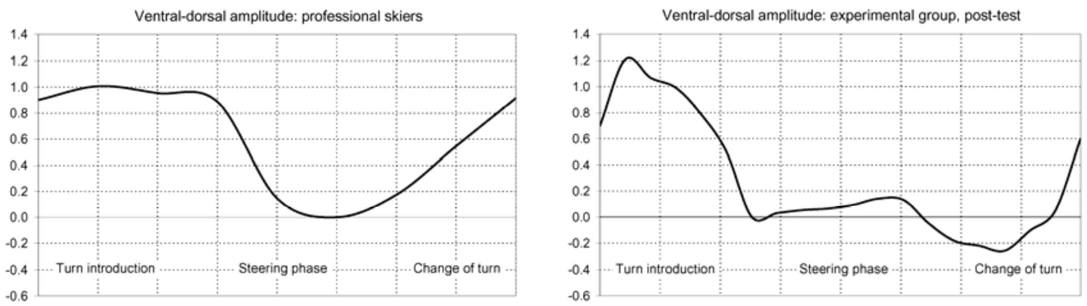



*Figure 5-26: Qualitative view of the ventral-dorsal body shift and amplitudes of the reference data obtained from professional skiers (left, max. positive amplitude A ≈ 1.0) compared to the results of the experimental group of the study (right, max. positive amplitude A ≈ 1.2 ). The data was offset to the steering phase values for this figure.*

The results of the subjects' impressions during the experiment are presented in the following section. The responses clarify how the audio training feedback was perceived and whether the support of the motion task also led to more intense emotional experiences.

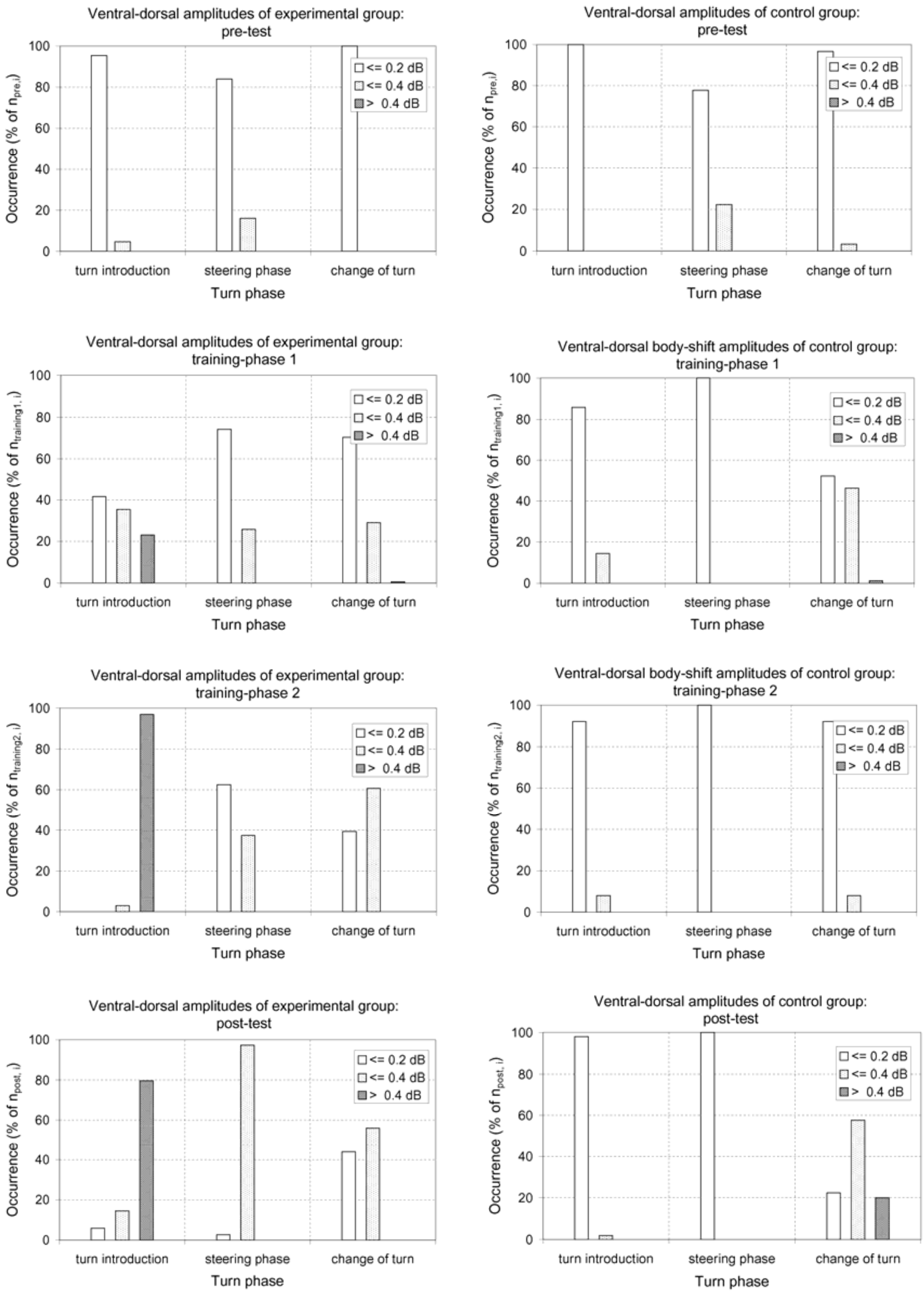



*Figure 5-27: Effect of audio training feedback on motor skills. The ventral-dorsal body shifts (amplitudes) for the turn introduction are shown to be more intense in the experimental group after they were subjected to feedback (training-phase 1 and training-phase 2, post-test).*

### 5.7.5 Subjective data: Results and discussion

Effect of the Digital Skiing Coach and confounding factors:

As summarized in Figure 5-28, the subjects of the experimental group showed a neutral response to the perceived effects of the Digital Skiing Coach. While the subjects stated that they felt the Digital Skiing Coach supported their motor activity fairly well, the ratings for the level of response to the audio feedback and the subjective impression of improvements in ski control were lower. This corresponds to the objective data because the data showed that the overall ventral-dorsal ratios improved only slightly while the overall effect on motor learning in terms of individual turns was substantial. It can be speculated that the duration of the experiment was too short to increase motor ability or substantially improve the skiing technique, and the effect of the audio training system was limited to short term improvements in the microcosm of a turn.

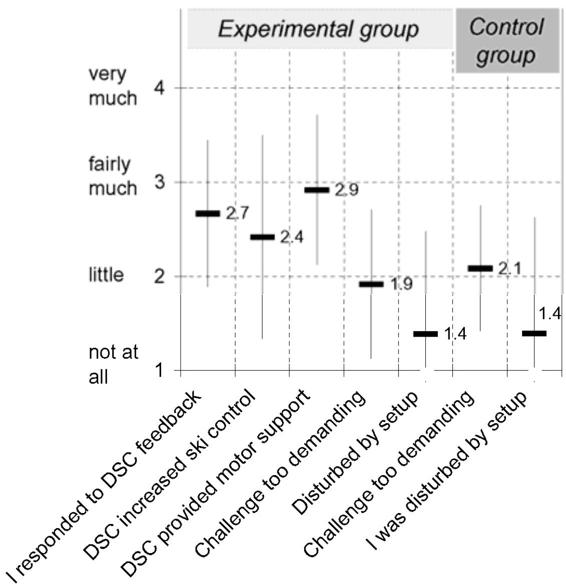



*Figure 5-28: Mean values of subjective impressions about the effects of the Digital Skiing Coach (DSC) on motor activity (only for experimental group) and regarding possible confounding factors during the experiment.*

Both experimental and control groups indicated that they did not find the experimental setup disturbing. This is especially encouraging for the experimental group because it was unclear whether skiers of beginner and intermediate skill level would respond well to the system. In comparison, the estimations regarding the aspiration level of the motion tasks were slightly higher, yet still on a low level. Confounding factors did not interfere according to the subjective responses of the subjects.

Lateral acceleration and fun experience:

Both sample groups stated that they were able to feel acceleration in the ski turns. The experimental group reportedly felt this sensation 13.3% more intensely than the control group. The effect that this sensation increased in the course of the experiment was rated equally by both sample groups but much lower. The level of enjoyment because of lateral acceleration was moderate for both sample groups, but 18.2 % higher in the experimental group compared to the control group. It is likely that lateral acceleration did not increase during the course of the present study and enjoyment in terms of a flow experience, therefore, was not experienced. The effect cannot be quantified because of a lack of information about the skiing speed, though. Consequently a correlation between the subjective perception of lateral acceleration and fun experience could not be established for the present study. Similarly, an effect could not be established with respect to an increasing lateral acceleration due to training feedback because both sample groups stated that the acceleration did only slightly increase. See also Figure 5-29 for the descriptive statistics.

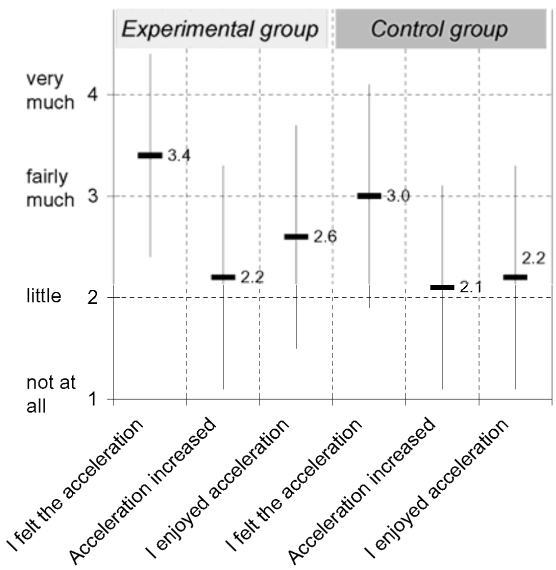



*Figure 5-29: Subjects' subjective impression regarding the side forces and resulting lateral acceleration in turns during the experiment.*

General elements of fun experience during the experiment: A different picture can be drawn concerning the emotional state and fun experience of the subjects (Figure 5-30). Both sample groups indicated that they enjoyed the downhill portions of the test cycles during the experiment. The reported intensity of this sensation was 8.6% for the control group compared to the experimental group. Regarding the fun experience resulting from audio feedback (or verbal instructions for the control group), the stimulation level reported by the experimental group was 10.3% greater than the control group. This may be an indicator that the audio training feedback system itself contributed to fun experience because it provided an amusing platform for motor learning feedback. The experimental group was slightly less satisfied with their performance than the control group, with a 6.9% difference in reported levels. This may be because of the fact that they felt unable to perform to a satisfactory level when faced with constant audio training feedback. This may suggest that the audio training feedback enhances ambition for mastery of the motor activity, and may ultimately lead to enhanced training. If such an effect is in fact observed in future studies, training feedback might be identified as a potential tool to elevate the activity level of athletic people by presenting them with a “challenge and conquer” scenario. In this sense, audio training feedback may represent a source of enjoyment for people who are driven by the motive of achievement.

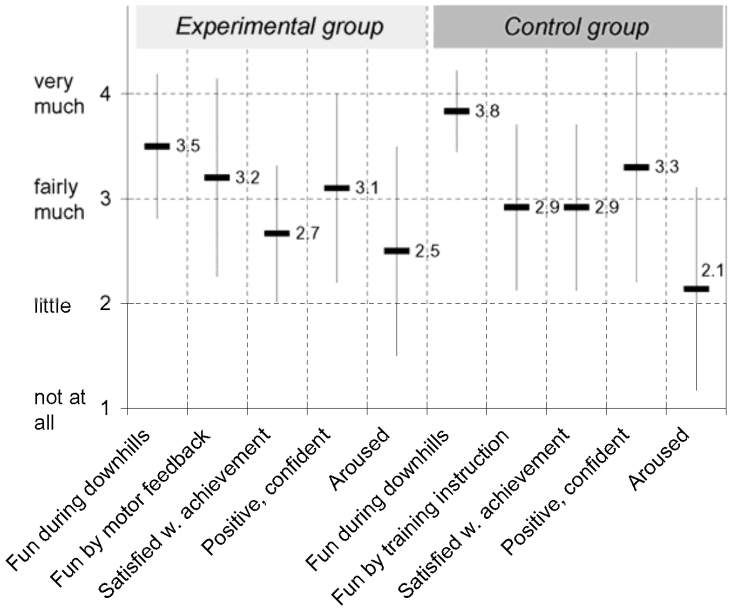



*Figure 5-30: Mean values of subjects’ emotional states during the experiment.*

Finally, arousal and the general emotional state were evaluated by averaging the corresponding responses from the questionnaire. Both sample groups felt somewhat positive and confident about the experiment, but only slightly aroused. It is possible that a state of flow experience could not be reached in the present study (above and beyond the connection between enjoyment and lateral acceleration). This inability to experience the flow state is most likely because of the challenging setup and the resulting level of intense concentration. Flow can only be experienced when a mental release is evident and the athlete and motor activity are in harmony. It is likely that an audio feedback training system would serve to enhance fun experience by providing an enjoyable user interface, but would not help the athlete achieve flow experience.

## 5.8 Outlook to the embodiment design of the sensor insole

To finalize the design process, a brief outlook on the embodiment design should be provided here with respect to potential applications. The embodiment design is based on requirements which were specified in the findings from the survey discussed in chapter 3 and on additional information that was obtained from the evaluation study. Improvements in the training algorithm are not outlined here.

Full integration of the sensor insole: To achieve simpler handing, manual on/off switching should be avoided. The embodiment design focused on the fully integrated sensor insole package including power supply (common coin cell battery) and enhanced functionality. The complete embedded system was implemented on a flexible circuit board that also incorporated the pressure sensors of the insole. Figure 5-31 depicts the slim shape of the integrated insole (left) and the embedded system, including power management, data processing and radio module on the flexible circuit board (right).

*Figure 5-31: Slim, fully integrated sensor insole package (left) that incorporates a flexible circuit board, including the embedded system and the foil pressure sensors (right).*

Enhanced functionality by intelligent power management: One example of the enhancement of functionality that was accomplished in the embodiment design is the application of power saving methods. For instance, the aforementioned acceleration sensor was not only used for the activation of the training feedback algorithm, but also for the activation of the sensor insole itself. The embedded system is put into a “deep sleep” mode in which the microprocessor checks for activity only every second and “wakes up” only when certain conditions of activity, namely a combination of specific data patterns on the pressure sensors and on the acceleration sensor, are perceived. Only then is the system set to normal operation mode. This feature negates the need for manual on/off switching and the insole can be completely isolated from environmental influences such as humidity because no external switch is required. In addition, it helps to significantly reduce power consumption. A variety of other methods were also incorporated to reduce the power consumption. Table 5-16 illustrates the effects of the different methods employed to help reduce power consumption and shows how a reduction in power consumption can greatly enhance the functionality of the system in terms of the usability of battery driven mechatronic systems.

*Table 5-16: Application of power-saving methods to the sensor insole and their effect on average power consumption and battery lifetime*

| *Power saving method* | *Average power consumption* | *Improvement in % from initial* | *Battery lifetime (hours / ski days)* |
|---|---|---|---|
| - No method | 12.0 mA | none | 16 h / 2.3 days |
| - Adjustment of radio transmission | 5.0 mA | 60.0 % | 40 h / 5.7 days |
| - Disabling functions not necessary in microcontroller | 2.6 mA | 20.0 % | 80 h / 11.0 days |
| - Smart enabling (only when skiing) | 1.1 mA | 12.5 % | 182 h / 26.0 days |
| - Enabling only in ski turns | 0.5 mA | 5.0 % | 400 h / 57.0 days |

By employing power saving methods, it is possible to reduced power consumption by 96% of the initial level. Depending on the different methods employed, this would in turn extend the battery lifetime from several hours to approximately 57 days with an average skiing time of seven hours per day.

## 5.9 Summary

This chapter was devoted to the application of the sport model to a design example from the field of mechatronic sports technology. The Digital Skiing Coach incorporates audio training feedback to help improve skiing technique. The purpose was to verify the feasibility, technical realization and practical applicability of the Digital Skiing Coach in terms of motor and emotional effects on the athlete. The ventral-dorsal body shift was identified as an essential element for mastering ski turns properly. In addition, literature findings suggested that audio feedback in terms of extrinsic, real-time knowledge of results (KP) feedback is best suited to motor learning in skiing. Further, the feasibility of sole pressure measurement for the analysis of basic characteristics of skiing technique was demonstrated. Data analysis of sole pressure measurements showed that the basic characteristics can be distinguished in terms of their quality, i.e. it is possible to distinguish good skiers from poor skiers. Prototype systems were designed and tested on the basis of these findings to evaluate the actual effect of audio training feedback in skiing.

The evaluation study revealed a variety of positive effects on the process of motor learning from the use of an audio training feedback system. It was shown that the training feedback produced two important effects. First, it is likely that the Digital Skiing Coach helped counteract fatigue effects so that the athletes could uphold appropriate motor activity for a longer period of time. This can help avoid poor motion technique resulting in potentially harmful effects. Second, audio training feedback was shown to help teach motor ability in terms of a ventral-dorsal shift of the body during the course of a ski turn. This effect was substantial for the experimental group while the control group did not display any systematic improvements. With respect to the subjective impressions of the study participants, it was stated that the ‘playful’ interface of the audio training feedback as a learning aid for the motor activity was a source of enjoyment itself. Further, the motion task requested of the athletes resulted in increased motivation to achieve, which in general may lead to increased training particularly when training feedback is used.

The study also showed that the application of such a system is restricted by a variety of limitations. First, the qualitative improvements in the ventral-dorsal body shift did not lead to a reproducible improvement in body position. It appears the improvements were limited to the phases were the subjects could concentrate on the audio training feedback, and therefore, no improvements of motor skills in terms of automatized motion patterns could be achieved through the present experimental setup. It is likely that a sustainable effect on skiing technique can only be achieved by longer periods of feedback training. The subjective impressions of the subjects suggest that fun experience in the sense of flow is very hard to achieve while using the Digital Skiing Coach because of the high level of concentration required.

Finally, an outlook was provided to the embodiment design of the prototype system.

# 6 Conclusions and outlook

This work contributed to the research in sports technology design for leisure sports by considering three key aspects of a sport context from an engineering perspective: the motivational background and emotional states of the athlete, the motion task of a certain sport and the functionality of sports technology.

What was the essence of the research background? The presented research is based on findings which were collected from the socio-cultural context of sport and scientific viewpoints. Sport today is a diverse field of activities with a clear trend towards individual and outdoor sports practiced in ad-hoc communities, e.g. mountain biking. The corresponding motion patterns emphasize the variety of motion in rotation and/or acceleration and strengthen the omnipresent claim for fun experience in leisure sports. Sport participation rates and the demographic change introduce new challenges in sports technology design. New designs need to account for individuals participating in sport after a period of absence, to enhance safety and to provide training support. The adaptation of methods in terms of training and motion support to the field of leisure sports was discussed as an opportunity for the introduction of new sports technology products, particularly by incorporating mechatronic systems. These new products would fulfill the need for training support in sports exercised individually. The combination of psychological and engineering methods for the evaluation of product features was identified as a major unsolved challenge in research related to the design of sports technology.

Which insights provided the different viewpoints on sport motives and product features? Surveys were conducted among sports technology manufacturers and sports retailers from the fields of skiing and mountain biking as well as athletes engaged in skiing to acquire the unique views of these specific sample groups. The survey results showed that fun experience is the most important motive in leisure sports, followed by achievement, wellbeing and health. Thrill and socializing motives were not considered as important as the previously mentioned motives. The ratings by the athletes varied greatly from the manufactures and retailers in regards to product features. While the athletes, for instance, stated that product function and functionality (e.g. failure-proof, handling or safety) is their main focus, the manufacturers emphasized product performance (e.g. weight). The potential for the use of mechatronic systems in sport was not rated equally among those surveyed. Sports retailers see great market potentials in beneficial training support and safety features. However, the sports technology manufacturers were skeptical and indicated that the capital expenditure is too high, the design knowledge is not available, and the market potential is remains unsettled. In contrast, 87% of the athletes stated that mechatronic systems have a high or very high potential for success in the market. Several prerequisites were identified by all of the sample groups as essential for market success, and include simple and intuitive handling, low power consumption and reasonable pricing.

Can fun experience be subjected to quantification for sports technology design? The experiments conducted to address quantification of fun experience during cycling and applications of the results to skiing were cutting-edge. Utilizing the findings from the surveys, a sport model was introduced that focused on the coherence of emotional states such as fun experience and motion characteristics of a certain sport and in combination with sports technology. The model takes into account both a sport context and sports activity. In sports technology design, it is important to consider the sport context, including the motivational background (e.g. fun or achievements) and the motion task (e.g. skiing technique), of a particular sport to clarify the specific design tasks and specify functionality of the design. In terms of sports activity, this means that the emotional (which originates in motivation), biomechanical (mechanical interfaces), cognitive (motor skills) and physical (physical strength) effects and interactions of sports technology on and with the athlete can be evaluated properly only on the basis of profound knowledge of the sport context. A study was conducted which analyzed the influence of lateral acceleration on fun experience while cycling on circular track with inclined curves. The experiment was designed such that the range of lateral acceleration observed during cycling was within the range of lateral acceleration displayed in leisure skiing. The study showed that lateral acceleration led to a higher perceived level of fun experience and that fun experience significantly increased when athletes were subjected to a higher lateral acceleration in curves.

What were the results of the application example? The third contribution of the thesis was the application of the sport model to the field of mechatronic sports technology. The main instances of the sport context, specifically sport motive and motion task, were clarified with respect to the design of an audio training feedback system for skiing. It was shown that the ventral-dorsal body shift is the main characteristic of proper ski turns. Additionally, it was determined that audio feedback is a feasible method to provide extrinsic training control for the skiers because the auditory analyzers of the human body are used less than other analyzers during skiing. In addition, sole pressure measurement was shown to be a valid method to quantitatively determine body shifts during skiing. It also serves to assess skiing technique qualitatively, which was a prerequisite for the design of the training feedback system.

As a second step, the focus of the study was shifted to sports activity and the evaluation of the training effect of the system concerning the enhancement of motor skills and fun experience. The experimental group, which was subjected to the audio feedback regarding ventral-dorsal body shift, was able to vary the body position during the course of a turn much more intensely than the control group which did not receive the feedback. Additionally, the experimental group displayed an enhanced overall performance regarding the ventral-dorsal shift. The experimental group was able to uphold a higher quality of the motor activity while the control group displayed indications of fatigue by the end of the experiment. The training method also triggered an increase in the level of fun experience based on the interaction with the feedback system. However, there was no evidence of an increased state of fun experience with respect to the lateral acceleration or the downhill runs themselves. Two reasons were identified that may influence this finding: First, it seems that audio training feedback requires a high degree of concentration which inhibits the flow experience and overall enjoyment. Second, the training period in the experiment was only half a day. This is likely an insufficient amount of time for the subjects to achieve a sustainable increase of speed and lateral acceleration in turns.

What generalizations can be made from the presented findings? The main focus of the present work was skiing; however, some of the findings were based on cycling. Therefore, the survey results from sports technology manufacturers, sports retailers and athletes can only provide valid information for the specific field with which they are directly associated. The training method introduced as part of the design application example was uniquely applied to skiing. However, some of the general results can be applied to other fields of leisure sports. The questionnaires developed within the present work provide valuable results for further applications. First, the surveys regarding sport motives, the importance of product features and other aspects concerning sports technology design provide a source of questions that can be incorporated into surveys in other fields of sport. The questionnaire developed for the quantification of fun experience in connection with lateral acceleration has since been successfully applied to kite-surfing (Kleiner, 2008). The sport model also provides a general, holistic view on the different instances of the sport context and sports activity in connection with sports technology. The model can be used for design guidance in arbitrary fields of sports technology design. Lastly, the promising results of the effect of audio training feedback on skiing technique can be applied to enhancing motor skills in many others areas of sport.

What are interesting aspects for further research? The present work concentrated on the quantification of fun experience with respect to lateral acceleration in the evaluation of sports technology. This aspect represents only a portion of the construct fun. A variety of other influencing factors were identified that may trigger fun experience. One example from the field of motion patterns is rotation. Further research is necessary to quantify the more complex interaction mechanisms of the different aspects of motion technique and fun experience. It is even possible that a “fun index” might be created with a more complete understanding of other factors influencing the fun experience. Such an index might then permit comparison of sports technology from radically different sports.

Research to date has only focused on a single aspect of skiing technique – the ventral-dorsal body shift. There are many other aspects of skiing technique, such as edging, that could benefit from the use of training feedback. Future research may also benefit from the expansion of the audio feedback system to the field of action approach learning mechanisms, such as the exaggeration of different body positions to enhance the sensation of motion. Finally, it was not shown if the training effect of the presented audio training feedback is sustainable. This very challenging field of research can include, as a starting point, a case study in skiing which clarifies the impact of a variation of the occurrence of the feedback and its retention effects.

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# 8 Appendix

## 8.1 Additional materials about the context of sports technology

### 8.1.1 Literature findings on definitions of sport

The brief literature overview which was presented as a basis for the definition of sport in the main part (chapter 2.1.1) of this thesis was extracted from a profound research on existing definitions of sport. The full results of this research are presented in the following and provide additional information about different viewpoints on sport.

Early definitions of sport at the beginning of the 20th century emphasized the typical traditional values of the "perfection of motion technique", the "aim for personal success" and the "comparison of strength" or "the battle for championship" (Hessen, 1908, p. 5; Steinitzer, 1910, p. 20). Interestingly, some authors already claimed the "character of pleasure" for sporting activities (e.g. Benary, 1913, p. 62). In the post World War Two epoch, the ideas of the "nonutility of physical activity", fairness, constituted in "the opponent as a friend in being on a comparable level of performance" and "the enhanced intensity of life" were added (Diem, 1949, p. 20; Gudenus, 1950, p. 11).

More recent attempts for a definition of sport take into account the change in the focus and the variety of sports. The advisory board of the German Sport Association (DSB) once pragmatically stated that sport can be described through its variety, characteristics, aims and goals. Thereafter, such descriptions can be obtained from the real world of sport – evident in opinions of the protagonists and organizations of sports, in functions of sports as well as through political, economical and other implications (Deutscher Sportbund, 1980, p. 437). On the basis of the DSB announcement, Hägele concretized some aspects of sport. First, the meaning of sport is only indirectly linked to the execution of motions, but directly embeds into the individual desires and needs. In such sense, sport has a social function as means of self-realization. Performance and competition thereafter should always be related to the individual – not the result itself, but the experience of performing is crucial. Such, also beginners are included into the understanding of sport. The social dimension of sport is described by Hägele as the ideal of attempting mutuality. In emphasizing the individual perspective, he is able to create his three level model of sport. The model is characterized by an authentic core of sporting ideals (motoric activity, performance display, meanings of sport such as self-realization and social interrelations), a second level of the "reality of sport", representing the current position and understanding of sport, and the third level of everything that is excluded from sport (according to Hägele, 1982, pp. 195ff). The three levels are regarded as a continuum.

This shows that there is obviously a gap between the ideals of sport and the practiced reality. The introductory considerations reveal some challenges in the attempt for a definition of sport: which types of activity should be called sport? Is competition a precondition for an activity to be called sport? Heinemann (1998, p. 33) names reasons for the controversy discussion. Different groups or institutions, for instance, by nature have a different viewpoint regarding sport. A nice walk can be sport for one person while sport for another one is nothing less than training for a marathon. Second, common conceptions of sport are changing with time. The understanding of sport 30 years ago was quite different to the idea we have today. Accordingly, sport as a social construct is created from the field of different meanings in which an activity is defined as sport.

It is the opinion of the author that a definition of sport should on the one hand provide precise indicators that can be used to distinguish between sport and other fields of activity. On the other hand, a definition must take into account recent tendencies that are manifest in the reality of sport. We will have a look at the essence of some author's definitions before we come to a final conclusion.

First, Volkamer (1987) provides an approach for a functional understanding of sport. Thereafter, sport is formed by rules. Rules are of social relevance with respect to human behaviour in social situations, they regulate activities, they can be subject to changes, and they are assured by sanctions, but can be violated. Digel (1982, p. 11) states analogously: "It is assumed that the rules of sport are the constitutive elements that reveal the typical characteristics of sport … and that sport can be separated from all other areas of our society through the interaction of its rules… it's the rules that let us understand sport". This means that a sport cannot be "played" without the rules. Obviously, soccer cannot be played without a ball and without a basic definition of the dimensions of the field and of what is counted as a goal or a foul. But what about other sports like skiing? The question may appear a bit provocative since the rules of skiing are more fuzzy and variable. But the concept of rules is just hidden on a different, more subtle level: it is still the ski and not a snowboard which is being used for going downhill and it is still snow and not rocks on which we are skiing. Furthermore, the concept of rules applies also for the definitive character of common understanding and generally accepted best practices for sports. They are deduced by scientific considerations of motor control, biomechanics or exercise prescription and supported by experience in teaching and performance sports. According to Piaget (1954), Searle (1971) and De Wachter (1983), constitutive rules are defining a new space of activity which would not be existing without the rules. According to this, sport is primarily determined by such constitutive rules in creating an artificial surrounding for the activities. For instance, the efforts of a 400m sprinter to run a course in as less time as possible to finish right at the starting-point may seem senseless from an objective point of view. If it was not sport, it would be a good idea to just stay at the starting-point.

Besides the functional view, a number of authors have published statements or definitions on sport including the competitive element of sport. In a later publication of the DSB, for instance, sport is proclaimed to be "a motion and body-oriented, comprehensive activity aiming for an overall development of the individual identity and enhances physical, psychological and social wellbeing." Further, sport should be driven by "the will to display performance, the need for comparison in terms of competition". Also, "health" and "the principles of sport" must be conserved (Deutscher Sportbund, 2000). The definition is much more open to the reality of sport and includes major characteristics, but the competitive aspect is regarded as essential. Also Tiedemann (2006) explicitly excludes areas of activity not aiming for competition. He names sport "a cultural field of activity" which is characterized by the "voluntary relation of humans to other people" to "consciously develop abilities" in the area of "skilled motion". The final goal of "comparison" under certain "rules" is achieved without "damaging". In Mandell's historic view on sport, it "encompasses competitive activity of the whole human body according to sets of rules for purposes ostensibly or symbolically set apart from the serious, essential aspects of life" (Mandell, 1984, p. 17). Rodgers (1977) from the Council of Europe includes the idea of competition as well and suggests three other basic elements of sport: "…involvement of physical activity", "recreational purposes" and a "framework of an institutional organization". On the background of a general tendency towards individualization and decentralization, especially the demand for institutional organizations appears not very feasible. The Council of Europe's Sports Charter uses a definition which is more open: "Sport means all forms of casual or organized physical activity" that "aim at expressing or improving physical fitness and mental well-being, forming social relationships or obtaining results in competitions at all levels" (Council of Europe, 1992). Steinkamp's definition of sport contains the elements "skills" that can be learned and accumulated to "performance" for solving "artificial tasks" by means of "physical activity". A sport is constituted by displaying such activity for the end in itself and voluntarily in the frame of competitions. He brings in the dual motive of sport, which on the one hand leads to the experience of motion and on the other hand to the improvement of skills (Steinkamp, 1983, p. 104). Also Heinemann (1998, p. 34) differentiates these elements of sports, "physical activity", "competitions" as "comparison of performance" and "sport specific sets of rules". In addition, he names the "nonutility" of sport, in the sense that the results are not aiming to generate a "product" in the very sense of its meaning, as another criterion.

Apart from the advocates of competition, some authors explained their view of sport as a "battle on the edge" or "the stage of the protagonists" which should be demonstrated by the following two examples. Among aspects like "publicity", "physical activity", "objective criteria" constituted as "rules" in "competitions", the nature of sport is described by Seel (1995, pp. 116ff) primarily as the attempt of the human to test their physical barriers given by nature. The obligation of the protagonist to perform the physical activity by himself, the absence of the possibility of delegation, is a fact Stichweh (1995, p. 17) takes as an indicator to distinguish sport from pure game.

Finally, there is a variety of author's including also non-competitive activities into their definitions. Some of their definitions will be presented in the following. Volkamer (1987, p. 53) defines sport very universal as "the random creation of tasks, problems or conflicts primarily solved by means of physical efforts." The solutions should be "reproducible" and "subject to improvement" as well as "not directly linked to material advantage". Grupe and Krüger (1998, p. 478) present their ethic view on sport and state that sport is considered as "physical activities, games and competitions" that can be performed under "intimate circumstances" or in the frame of "major organizations and institutions". Further, "sport today is also associated with physical activities that reach beyond the traditional comprehension of sport as a matter of performance and competition". Grieswelle (1978, p. 29) defines sport as "activities dominated by physical action" and a focus on "motoric skills which can be learned and practiced" as well as "precisely aiming for performance on the basis of predefined quality criteria". The sociological view of Weis (2003, p. 364) provides "sport as a system of action, providing sense" and as "part of social life and a social institution". Sport refers to "physical and social activity that is practiced under game-like conditions as competitions between two or more participants or against nature after a certain set of rules. Hereby, it is not the physical activity or effort itself that distinguishes sport from work but rather the symbolic essence of sport. …". According to Voigt (1992, p. 144), sport is the "deliberate motion of the human body" as a response to consciously created tasks which is "guided by the principle of performance, urge-oriented, emphasizing pleasure, hedonistic, body-centered" and guided by "values, goals, norms and sanctions" that could be interpreted as a synonym for rules. Lüschen (1972, p. 212f.) calls sport a generic term for all sorts of competitive games. "Physical skills", the "interaction with others" and the existence of "rules" are named as characteristics. In a similar way, sport is defined by Bernett (1972, p. 212). He elaborates more detailed on the aspect of "aiming for motoric skills" and "performance display".

The following list represents the essence of these contents. Thereafter, sport is

- a motion and body-oriented activity containing motoric aspects,
- constituted by rules as quality criteria for achieving artificial tasks,
- voluntary,
- characterized by performance display and direct or indirect competition,
- interaction between humans or between human and nature,
- cultural field providing individual sense and symbolic essence like wellbeing, pleasure, self-realization or health,
- exercised without damaging and played after the principle of fairness,
- and characterized by material nonutility.

In the opinion of the author, the precondition that exercising sport may not cause damage to oneself or to others seems to be problematic. There are several examples of traditional and newer sports (e.g. boxing) were the possibility of harm of the opponent cannot be completely avoided. This of course does not mean that the principle of fairness can be ignored and the term most likely refers to the fact that harm must not be caused intentionally and beyond the rules of the certain sport. A boxer, for example, is not allowed to hit the opponent beyond the waist. A bicycle racer is not allowed to push his opponent aside during a sprint. Apart from that, many sports by nature are connected to personal risks like a damaged crucial ligament in soccer, a broken leg in skiing, an injured finger in climbing or a graze from a crash in cycling. For these reasons, the expression “without damage” was left out and replaced by “by fair means” which represents the actual intention of sports much better.

From these major aspects of sport, a definition of sport was drawn for the context of this thesis (see chapter 2.1.1).

It should be mentioned that, besides approaches for a universal definition of sport, attempts can be found which try to differentiate sport regarding single aspects, e.g. competitive sport, leisure sport, health sport, etc.. Holzke (2001), just to name one example, provides a very profound elaboration on the definition of different aspects of sport in the context of law. Apart from that, sports are frequently distinguished by their degree of novelty or by the risks involved in exercising these sports. Wopp (2003, p. 94) undertakes an attempt to define so called “trend sports” and Schwier (2003, p. 21) further categorizes trend sports into “fitness”, “risk sports” and “fun sports”.

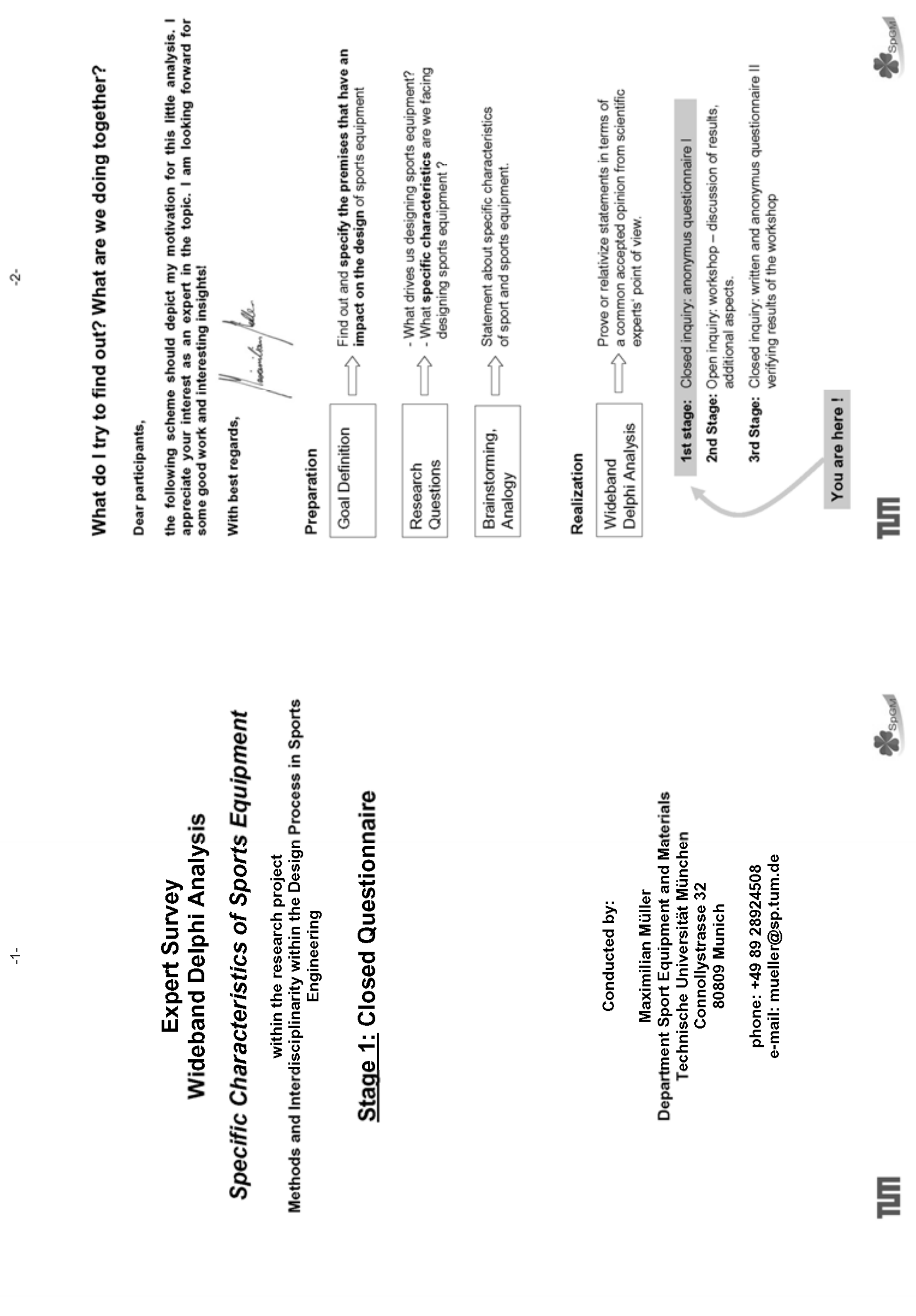
With regard to the focus of the present thesis, the superordinate term trend sport was considered in addition to the general definition of sport. Trend sport is an omnipresent term in the public perception as a synonym for new tendencies in sport. It is obviously used as a synonym for a variety of newer sports (e.g. also for the abovementioned risk sports, fun sports, etc.) and general tendencies in sport which thirdly seem to play a key role in understanding the values of sport in the modern society. Although the term does not seem to exist in the English speaking community, it is frequently used in the German speaking countries.

Wopp (2003, p. 93f.) tried a definition of the term trend sport and presented some basic elements of the term trend. Thereafter, trends are firstly the basic focus of developments which are formulated as metaphors. Second, trends describe complex, multidimensional phenomena in the society which comprehend major parts of the population and affect purchase decisions, politics and activities in a sustainable way. And finally third, trends are based on interrelations of different factors that form a specific conjunction of patterns. He finally states that trend sports are market relevant combinations of known conditional elements. Lamprecht and Stamm (1998) concretize the term trend sport as lifestyle oriented forms of activity which bear great potential of a wider dissemination as “charismatic products”. Schwier (2003) continues and adds that trends in sport are characterized by an exceeding of the common understandings of sport and thus put in perspective formerly unknown or unattended interpretations of human motion. According to the elaborations of the abovementioned authors, a trend sport can be regarded as a market relevant combination of known elements of human motion.

The further differentiation of sport into risk sport etc. can not totally be agreed with in the understanding of sport used in this thesis. A good example is climbing which is often assigned to high risk sports. This does not justice to the characteristics of the sport today. Climbing is on the way to become, if not already is, a leisure sport. It is feasible for families in climbing-halls with artificial walls and excellent safety standards and at the same time vanishing point for protagonists of the extreme. The example should point out that it is often a question of the abovementioned viewpoint when it comes to a judgement about the nature of a certain sport. For the present context, the term trend sport embraces all newer tendencies in sport and acts as an antipole to the understanding of traditional sports.

### 8.1.2 First questionnaire of the expert survey

The following questionnaire was presented to the participants of the Delphi analysis which was conducted to explore a rough orientation regarding different viewpoints in science concerning characteristics of sports technology.



-1-

**Expert Survey**
**Wideband Delphi Analysis**

***Specific Characteristics of Sports Equipment***

**within the research project**
**Methods and Interdisciplinarity within the Design Process in Sports Engineering**

**<u>Stage 1:</u> Closed Questionnaire**

**Conducted by:**

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**What do I try to find out? What are we doing together?**

**Dear participants,**

**the following scheme should depict my motivation for this little analysis. I appreciate your interest as an expert in the topic. I am looking forward for some good work and interesting insights!**

**With best regards,**

**Preparation**

Goal Definition ⇨ Find out and **specify the premises that have an impact on the design** of sports equipment

Research Questions ⇨ - What drives us designing sports equipment?
- What **specific characteristics** are we facing designing sports equipment ?

Brainstorming, Analogy ⇨ Statement about specific characteristics of sport and sports equipment.

**Realization**

Wideband Delphi Analysis ⇨ Prove or relativize statements in terms of a common accepted opinion from scientific experts' point of view.

**1st stage:** Closed inquiry: anonymus questionnaire I
**2nd Stage:** Open inquiry: workshop – discussion of results, additional aspects.
**3rd Stage:** Closed inquiry: written and anonymus questionnaire II verifying results of the workshop

**You are here !**

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## 1. Information about the expert

Please answer the following questions about your professional background and research topics!

1.1 My original education is

Please note your final degree

1.2 Now, I am working in the following field

1. ☐ **Social Science**
2. ☐ **Natural Science**
3. ☐ **Design/Art Science**
4. ☐ **Human Science**
5. ☐ **Engineering Science**
6. ☐ **Education/Coaching**
7. ☐ **Others**

1.3 My specialization within this field is (e.g. training science)

1.4 My focus topic within this specialization is

1.5 I am concerned with sports in the following way(s) as a

1. ☐ **Trainer**
2. ☐ **Scientist**
3. ☐ **Athlete**
4. ☐ **Designer**
5. ☐ **Others**

1.6 My position at the moment is (e.g. research assistant)

-4-

**Definition of sports equipment:** any object used for a particular sports or exercise

## 2. Warming up

Please answer the following question with respect to the field of leisure sports according to your personal knowledge and experience spontaneously!

What do you think is special about sports equipment compared to other products? If possible make **3 statements**!

The aspects under the following topics do not state a complete list. If you can think of additional aspects please note these and come back to them in the workshop!

**3. Questions on the variety of different aspects influencing the design of sports equipment**

Please answer the following questions with respect to the field of leisure sports according to your personal knowledge and experience!

1Fun as an enjoyable activity in relation to sports is dependent on the environment!

| 1. I totally agree | 2. I partially agree | 3. I partially disagree | 4. I totally disagree | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

2Fun as an enjoyable activity in relation to sports is dependent on the kind of motion!

| 1. I totally agree | 2. I partially agree | 3. I partially disagree | 4. I totally disagree | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

3Fun as an enjoyable activity in relation to sports is dependent on the sports equipment!

| 1. I totally agree | 2. I partially agree | 3. I partially disagree | 4. I totally disagree | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

4In your opinion, how much is fun a driving force to use special sports equipment compared to the use of a special automobile?

| 1. Much stronger | 2. Partly stronger | 3. Weaker | 4. Almost not present | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |





Equipment addressing only a certain group (e.g. only women) leads to social exclusion effects!

| 1. I totally agree | 2. I partially agree | 3. I partially disagree | 4. I totally disagree | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Socialization effects of sports equipment can be induced through group specific design!

| 1. I totally agree | 2. I partially agree | 3. I partially disagree | 4. I totally disagree | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

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How do you estimate the current occurrence of socializing effects of sports equipment compared to "regular" fashion?

| 1. Much stronger | 2. Partly stronger | 3. Weaker | 4. Almost not present | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

In your opinion, what is the impact of trend sports (e.g. freeclimbing) on consumer behaviour?

| 1. Much stronger | 2. Partly stronger | 3. Weaker | 4. Almost not present | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

In your opinion, what is the impact of sports trends (e.g. carving-skis) on consumer behaviour?

| 1. Very strong | 2. Fairly strong | 3. Little | 4. Almost not present | 5. I can't make a statement |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

-8-

In your opinion, what influence has the product development / design side on trends in sports?

1. ☐ **Very strong**
2. ☐ **Fairly strong**
3. ☐ **Little strong**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

Sports equipment is used for individualization!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

People using certain sports equipment are put into certain social schemes!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

-9-

Compared to the purchase of an automobile, do you think the purchase of a certain sports equipment is socially polarizing?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

Sports accidents are taken into account by the athlete due to the positive effect of personal safety equipment!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Possible crashes during sports and their consequences are often blinded out by athletes!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

-10-

In comparison to the safety package of automobiles, what role do you think the importance of safety aspects plays for sports equipment?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

Sports equipment is an auxiliary of prevention against harm!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Sports equipment is a means of rehabilitation after desease or surgery

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

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Sports equipment is used as means of compensation of office work!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

The creation of new sports equipment is mainly due to the individual inventiveness of "freaks" making their own prototypes!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Athletes without technical or scientific background cannot design sports equipment that successfully meets market requirements!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

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How do you estimate the influence of single inventors on the design of sports equipment compared to household devices?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

Compared to consumer electronics industry, what importance do short innovation cycles have for sports equipment?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

How do you estimate the importance of leightweight structures on the design of sports equipment compared to the impact on the design of automobiles?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

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How do you estimate the importance of highly dynamic loading cases on the design of sports equipment compared to the impact on the design of automobiles?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

The design of sports equipment is limited by primary legal restrictions!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Form and function of sports equipment is up to the designer and free from constraints through laws!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

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Compared to automobile industry, how do you estimate the influence of legal restrictions on the sports industry?

1. ☐ **Much stronger**
2. ☐ **Partly stronger**
3. ☐ **Partly less stronger**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

Sports accessories (information devices, fashion, transportation devices) are an additional attraction to practice certain sports!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

The variety of available extras around a piece of sport equipment does not influence the extent of its utilization!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Special education is obliging for using a piece of sports equipment!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Sports equipment can be used in the proper environment without restrictions!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**



## 4. Questions on the complexity of focus of different aspects influencing the design of sports equipment

For many of the aspects influencing the design of sports equipment a wide range of values is possible.
Please answer the following questions with respect to the field of leisure sports according to your personal knowledge and experience!

How would you estimate the expenses for the development of sports equipment compared to the development of an average consumer good (e.g. cell phone)?

How do you estimate the impact of successful equipment coming from competitive sports on the use of its analog in leisure sports?

1. ☐ **Very strong**
2. ☐ **Fairly strong**
3. ☐ **Little strong**
4. ☐ **Almost not present**
5. ☐ **I can't make a statement**

How do you think should the response to the athlete of a good sports device be like?

1. ☐ **Very strong**
2. ☐ **Fairly strong**
3. ☐ **Little strong**
4. ☐ **Almost not present**
5. ☐ **A combination of 1. to 4. can be applicable**
6. ☐ **I can't make a statement**

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How do you estimate the occurrence of tendencies towards mass customization to fit user expectations?

1. ☐ **Very strong**
2. ☐ **Fairly strong**
3. ☐ **Little strong**
4. ☐ **Almost not present**
5. ☐ **A combination of 1. to 4. can be applicable**
6. ☐ **I can't make a statement**

The user of sports equipment tolerates fails of product specifications!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

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## 4. Questions on the interaction of aspects influencing the design of sports equipment

The different aspects that influence the design of sports equipment interact between each other in a certain way.
Please answer the following questions with respect to the field of leisure sports according to your personal knowledge and experience!

Stimulating thrills (e.g. very dynamic movements) cause psychological addiction!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

Fun sports (e.g. sports climbing) are mainly practiced occasionally!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

The design of sports equipment is more driven by form than by function!

1. ☐ **I totally agree**
2. ☐ **I partially agree**
3. ☐ **I partially disagree**
4. ☐ **I totally disagree**
5. ☐ **I can't make a statement**

-19-

Color and shape trends dominate the design of sports equipment!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

The performance display of a leisure sports athlete is directly related to his physiological gross efficiency!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

The increase of individual performance is more due to muscle strengthening for leisure sports!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

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The adaptability of sports equipment to individual antropometry is important for its market success!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

Different body types of the user are not taken into account to a satisfying extent for sports equipment!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

Sports equipment with insufficient ergonomic design is not accepted by the user!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

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-21-

The interface configuration between user and equipment is important for the market success of the equipment

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

Ambitious sportive motion in terms of the motor activity is regarded as a challenge by the user!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

Sports with simple engrams are popular!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

-22-

The latest sports equipment is regarded as an instrument to improve the personal performance!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

For leisure sports the users rely more on proper training than on new sports equipment to enhance their activity!

1. ☐ I totally agree
2. ☐ I partially agree
3. ☐ I partially disagree
4. ☐ I totally disagree
5. ☐ I can't make a statement

Thank you very much for filling out the 1st questionnaire !
See you on November the 13th 2006 for the workshop !

### 8.1.3 Second questionnaire of the expert survey

The following questionnaire was presented to the participants in a second step of the Delphi analysis which was conducted to explore specific items concerning characteristics of sports technology.

-1-

**Expert Survey**
**Wideband Delphi Analysis**
***Specific Characteristics of Sports Equipment***

within the research project
Methods and Interdisciplinarity within the Design Process in Sports Engineering

**Stage 3: Closed Questionnaire II**

Conducted by:

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-2-

**What do I try to find out? What are we doing together?**

Dear participants,

the following scheme should depict my motivation for this little analysis. I appreciate your interest as an expert in the topic. I am looking forward for some good work and interesting insights!

With best regards,

**Preparation**

Goal Definition → Find out and specify the premises that have an impact on the design of sports equipment

Research Questions → - What drives us designing sports equipment?
- What specific characteristics are we facing designing sports equipment ?

Brainstorming,Analogy → Statement about specific characteristics of sport and sports equipment.

**Realization**

Delphi analysis → Prove or relativize statements in terms of a common accepted opinion from scientific experts' point of view.

**1st stage:** Closed inquiry: anonymus questionnaire I
**2nd Stage:** Open inquiry: workshop – discussion of results, additional aspects.
**3rd Stage:** Closed inquiry: written and anonymus questionnaire II verifying results of the workshop

You are here !

-3-

## 1. Information about the expert

Please provide some personal information about you and some sports- and professional-related topics!

1.1 I practice or practiced sports myself on the level of

1. ☐ **High Performance Sports** 2. ☐ **Performance/ Amateur Sports** 3. ☐ **Leisure Sports**

1.2 My favorite sports is (are)

1.3 My professional field of interest/research related to sports is

1.4 Please name 2 colleagues from other departments, but working in the same field, you would recommend as specialists in this very field

| Name | Department |
|---|---|
| | |
| | |

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## 2. Question on Motivation and Fun in Sports

Please answer the following question with respect to the field of leisure sports according to your personal knowledge and experience spontaneously!

2.1 What is your understanding of motivation?

2.2 What is your understanding of fun?

2.3 Regardless the level of skills of the people performing the sports, point out, if applicable, differences between trend-sports (e.g. kite-surfing, inline skating) and traditional sports (e.g. cycling or soccer) regarding the following aspects:

Kind of motion

Type of equipment

2.4 Please describe your opinion about the relation of fun and risk in sports regarding the aspects environment and equipment?

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2.5 In your opinion, what are the reasons for specific leisure sports equipment (also for completely new types of sports) being or becoming popular?

2.6 How is fun, in your opinion, related to the sports equipment of a specific sports. Please give examples!

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**3. Question on Safety in Sports**

3.1 Give examples of aspects related to the safety of sports equipment that in your opinion or from your experience should be covered by official restrictions (laws, e.g. the biggest kite for surfing)!

3.2 What do you think about obligatory professional education in sports regarding the use of sports equipment (e.g. a "drivers licence" to handle sports equipment xy)? Give, if possible, examples where this, in your opinion, would make sense!

3.3 Do you think that the occurrence of accidents is taken into account consciously in some sports? Please give, if possible, examples of such sports and the consequences for the sports equipment!

3.4 From your experience, what is the difference between performance sports and leisure sports regarding risks?

3.5 What can you say about the consciousness of sportive people (leisure sports) and athletes (performance sports) regarding causes and mechanisms of longterm harms to their body?

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**4. Questions on the Interface Human – Equipment**

4.1 Give, if possible, each examples of sports equipment where the adaptability to the antropometry of the user is important / not important. Please describe the affected body parts.

4.2 Think of equipment where the feedback to the user should either be adjustable (e.g. rear damper in a bicycle from "hard" to "soft") in a wide range or just very direct or just very indirect. Please give an example!

4.3 What aspects of sports equipment would be important for individualizing the equipment to the user apart from antropometry?

THANK YOU FOR ANSWERING MY QUESTIONS !

I WELCOME YOU ON WEDNESDAY, 23rd May 2007

## 8.2 Additional materials on the analysis of sport motives and product features

### 8.2.1 Questionnaire of the survey among sports technology manufacturers

The following questionnaire was presented to selected sports technology manufacturers in an internet survey. The questionnaire was identical for the mountain bike and the alpine ski sector, except for reference of the product group. The results were used to explore the application of methods, driving forces and obstacles for new product designs, key product features and user oriented motives in product design.

Overall number:

Number alpine-skis:

**How many employees is your company engaging at the moment?**

Employees in the company: ______ Persons

5 [Seiten-ID: 446888] [L]

Strategie und Portfolio

## *2. Let's switch to some questions about the strategy and the product portfolio of your company.*

**What are your main product groups and to what extent are the following divisions represented in your company respectively?**

Please provide information to what degree the following divisions contribute:

Alpine ______ %

Nordic ______ %

**Where do product ideas emerge in your company?**

Multiple choice possible!!

- [ ] Spontaneous ideas of employees
- [ ] Application of methods: ______ (Please specify!)
- [ ] Benchmarking
- [ ] Customer input
- [ ] Other: ______ (Please specify!)

**How many optimizing designs of alpine-skis were conducted in your company in 2006?**

An optimizing design is assumed when only details of an existing product are modified.
Example: Redesign of coating, face-lift

Number 2006: ______

**What was the focus of optimizing designs?**

Please estimate the priority of the following factors.

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Reduce costs | ○ | ○ | ○ | ○ |
| Performance (Weight, stiffness, etc.) | ○ | ○ | ○ | ○ |
| Adaption to market trends (Design, safety, etc.) | ○ | ○ | ○ | ○ |
| Change of technology (Adaption to new production technology, etc.) | ○ | ○ | ○ | ○ |
| Other: ______ (Please specify!) | ○ | ○ | ○ | ○ |

**How many new designs of alpine-skis were conducted in your company in 2006?**

A new design is assumed when a concept of a new product is established that is different from existing products in major aspects.
Example: new overall structure, of ski body

Number 2006: ______

**What was the focus of new designs?**

Please estimate the priority of the following factors.

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Reduce costs | ○ | ○ | ○ | ○ |
| Performance (Weight, stiffness, etc.) | ○ | ○ | ○ | ○ |
| Adaption to market trends (Design, safety, etc.) | ○ | ○ | ○ | ○ |
| Change of technology (Adaption to new production technology, etc.) | ○ | ○ | ○ | ○ |
| Other: ______ (Please specify!) | ○ | ○ | ○ | ○ |

**How long took the last innovation-cycle of a new design of alpine-skis?**

An innovation-cycle is regarded as the time between the market introduction of two consecutive models of a product line.

Period of innovation cycle: ______ Months

**How long took the development period of the last new design of alpine-skis?**

The development period is regarded as the time from the first listing of requirements to the market launch.

Development period: ______ Months

**Please specify the sturcture of your alpine-ski portfolio regarding the point of market**

**launch!**
Without optimizing designs / face-lifts
**What is the turnover of products that...**
...less than 1 year on market? ____ % of overall turnover
...up to 2 years on market? ____ % of overall turnover
...more than 2 years on market? ____ % of overall turnover

6 [Seiten-ID: 446889] [L]

Limitierende Faktoren

### 3. The following section is about the limiting factors that you are facing during the realization of product innovations.

**In your opinion, what are the constraints for the realization of product innovations in your company?**
Multiple choice possible!

**Finding ideas**
- ☐ Lack of innovative ideas
- ☐ Lack of application of methods
- ☐ Other: ____ (Please specify!)

**Legal restrictions**
- ☐ Restrictions due to legal formalities

**Research and Development**
- ☐ Lack of experience in treating new ideas
- ☐ Lack of cooperation with external experts/partners
- ☐ Limited human ressources/ limited timeframe
- ☐ Required investments too high
- ☐ Other: ____ (Please specify!)

**Production**
- ☐ Lack of experience in treating new technologies
- ☐ Other: ____ (Please specify!)

**Marketing, Sales**
- ☐ Innovation are not supported
- ☐ Other: ____ (Please specify!)

7 [Seiten-ID: 446890] [L]

Produktentwicklung

### 4. The following section is about several aspects of the product development itself.

### 4.1 We start with some general information about product development in your company.

**What was the investment for research and development in 2006?**
Overall investment: ____ % of turnover
R&D alpine skis: ____ % of turnover

**In your company, how many employees work on technical developments of alpine skis?**
Number of employess: ____ Persons

**Do you have different workgroups in your R&D division? (e.g. for alpine skis, nordic, etc.)**
Multiple choice possible!
- ☐ Alpine
- ☐ Nordic
- ☐ No

**How is your R&D division for alpine skis organized?**





Multiple choice possible!
- ☐ Regarding product (One team is responsible for the whole development)
- ☐ Regarding steps of development (Employees or teams are responsible only for one certain step of development, e.g. CAD layout, design, etc.)
- ☐ No fixed organization structure
- ☐ Other: ____ (Please specify!)

**What was the scope of engineering in the field of alpine skis in your company in 2006?**
Please provide a percentage estimation of how much of the engineering taks were done by your company itself!
We did ____ % of the engineering tasks by ourselfes.

**To what extent do you use external services and what are the partners you collaborate with?**
Please provide a ranking of the importance of the following (possible) partners for the steps of development!

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| **Research: Basic studies (e.g. material sciences)** | | | | |
| University | ○ | ○ | ○ | ○ |
| Service company | ○ | ○ | ○ | ○ |
| Consulting company | ○ | ○ | ○ | ○ |
| Other: ____ (Please specify!) | ○ | ○ | ○ | ○ |
| **Development: Applied tasks (e.g. layout and structural analysis of a ski)** | | | | |
| University | ○ | ○ | ○ | ○ |
| Service company | ○ | ○ | ○ | ○ |
| Consulting company | ○ | ○ | ○ | ○ |
| Other: ____ (Please specify!) | ○ | ○ | ○ | ○ |
| **Product tests (e.g. testing of endurance and strength of material, field tests etc.)** | | | | |
| University | ○ | ○ | ○ | ○ |
| Service company | ○ | ○ | ○ | ○ |
| Consulting company | ○ | ○ | ○ | ○ |
| Privat person/ tester | ○ | ○ | ○ | ○ |
| Other: ____ (Please specify!) | ○ | ○ | ○ | ○ |
| **Other** | | | | |
| Please specify category "Other": ____ | ○ | ○ | ○ | ○ |
| University | ○ | ○ | ○ | ○ |
| Service company | ○ | ○ | ○ | ○ |
| Consulting company | ○ | ○ | ○ | ○ |
| Privat person/ tester | ○ | ○ | ○ | ○ |
| Other: ____ (Please specify!) | ○ | ○ | ○ | ○ |

8 [Seiten-ID: 446891] [L]

Produktentwicklung 2

### 4.2 In the following we ask you to provide some information about the core topics of product development in your company.

**How are the following core topics of product development treated und where is the main focus?**

**Durability**
Layout of parts and calculation/evaluation of durability of parts regarding failure.

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**...is treated by:**
**Use of research methods (analysis):**
- ☐ Motion analysis
- ☐ Interview (or questionnaire)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Performance diagnostics

- ☐ Other: (Please specify!)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods that support the design process:**

- ☐ List of requirements
- ☐ Design matrices
- ☐ Functional structure
- ☐ Other: (Please specify!)
- ☐ Brainstorming
- ☐ Inquiry (standard parts, solutions available, competitors, etc.)
- ☐ Construction/design catalogues
- ☐ Other: (Please specify!)
- ☐ Structuring schemes (z.B. morphologic box)
- ☐ Assessment schemes
- ☐ ABC Analysis
- ☐ Other: (Please specify!)

**Use of methods in the development (synthesis):**

- ☐ Test
- ☐ Other: (Please specify!)
- ☐ Construction/design
- ☐ Other: (Please specify!)
- ☐ Calculation
- ☐ Other: (Please specify!)

## Functional safety

Usage without dysfunction, i.e. product "works" properly.

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**...is treated by:**

**Use of research methods (analysis):**

- ☐ Motion analysis
- ☐ Performance diagnostics
- ☐ Other: (Please specify!)
- ☐ Interview (or questionnaire)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods that support the design process:**

- ☐ List of requirements
- ☐ Design matrices
- ☐ Functional structure
- ☐ Other: (Please specify!)
- ☐ Brainstorming
- ☐ Inquiry (standard parts, solutions available, competitors, etc.)
- ☐ Construction/design catalogues
- ☐ Other: (Please specify!)
- ☐ Structuring schemes (z.B. morphologic box)
- ☐ Assessment schemes
- ☐ ABC Analysis
- ☐ Other: (Please specify!)

**Use of methods in the development (synthesis):**

- ☐ Test
- ☐ Other: (Please specify!)
- ☐ Construction/design
- ☐ Other: (Please specify!)
- ☐ Calculation
- ☐ Other: (Please specify!)

## Optical design (color, shape, etc.)

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**...is treated by:**

**Use of research methods (analysis):**

- ☐ Motion analysis
- ☐ Performance diagnostics
- ☐ Other: (Please specify!)
- ☐ Interview (or questionnaire)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods to support the design process:**

- ☐ List of requirements
- ☐ Design matrices
- ☐ Functional structure
- ☐ Other: (Please specify!)
- ☐ Brainstorming
- ☐ Inquiry (standard parts, solutions available, competitors, etc.)
- ☐ Construction/design catalogues
- ☐ Other: (Please specify!)
- ☐ Structuring schemes (z.B. morphologic box)
- ☐ Assessment schemes
- ☐ ABC Analysis
- ☐ Other: (Please specify!)

**Use of methods in the development (synthesis):**





- ☐ Test
- ☐ Other: (Please specify!)
- ☐ Construction/design
- ☐ Other: (Please specify!)
- ☐ Calculation
- ☐ Other: (Please specify!)

## Ergonomy (design conform to human body conditions, minimizing discomfort and false movements)

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**...is treated by:**

**Use of research methods (analysis):**

- ☐ Motion analysis
- ☐ Performance diagnostics
- ☐ Other: (Please specify!)
- ☐ Interview (or questionnaire)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods that support the design process:**

- ☐ List of requirements
- ☐ Design matrices
- ☐ Functional structure
- ☐ Other: (Please specify!)
- ☐ Brainstorming
- ☐ Inquiry (standard parts, solutions available, competitors, etc.)
- ☐ Construction/design catalogues
- ☐ Other: (Please specify!)
- ☐ Structuring schemes (z.B. morphologic box)
- ☐ Assessment schemes
- ☐ ABC Analysis
- ☐ Other: (Please specify!)

**Use of methods in the development (synthesis):**

- ☐ Test
- ☐ Other: (Please specify!)
- ☐ Construction/design
- ☐ Other: (Please specify!)
- ☐ Calculation
- ☐ Other: (Please specify!)

## Fun aspect of using your products

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**Use of research methods (analysis):**

- ☐ Motion analysis
- ☐ Performance diagnostics
- ☐ Other: (Please specify!)
- ☐ Interview (or questionnaire)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods that support the design process:**

- ☐ List of requirements
- ☐ Design matrices
- ☐ Functional structure
- ☐ Other: (Please specify!)
- ☐ Brainstorming
- ☐ Inquiry (standard parts, solutions available, competitors, etc.)
- ☐ Construction/design catalogues
- ☐ Other: (Please specify!)
- ☐ Structuring schemes (z.B. morphologic box)
- ☐ Assessment schemes
- ☐ ABC Analysis
- ☐ Other: (Please specify!)

**Use of methods in the development (synthesis):**

- ☐ Test
- ☐ Other: (Please specify!)
- ☐ Construction/design
- ☐ Other: (Please specify!)
- ☐ Calculation
- ☐ Other: (Please specify!)

## Performance (weight, stiffness, etc.)

| | very important | important | not important | not relevant |
|---|---|---|---|---|
| Rating: | ○ | ○ | ○ | ○ |

**Use of research methods (analysis):**

- ☐ Motion analysis
- ☐ Performance diagnostics
- ☐ Other: (Please specify!)
- ☐ Interview (or questionnaire)
- ☐ Anthropometry analysis: measures of body segments
- ☐ Other: (Please specify!)
- ☐ Measurement of loads (forces/pressure, etc.)
- ☐ Modelling and simulation
- ☐ Other: (Please specify!)

**Use of methods to support the design process:**

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- List of requirements
- Design matrices
- Functional structure
- Other: (Please specify!)
- Brainstorming
- Inquiry (standard parts, solutions available, competitors, etc.)
- Construction/design catalogues
- Other: (Please specify!)
- Structuring schemes (z.B. morphologic box)
- Assessment schemes
- ABC Analysis
- Other: (Please specify!)

**Use of methods in the development (synthesis):**

- Test
- Other: (Please specify!)
- Construction/design
- Other: (Please specify!)
- Calculation
- Other: (Please specify!)

**Please establish a ranking about the importance of the listed topics for product development in your company!**

Rank the following topics regarding their importance (less important topics downwards).
The title blocks can be moved via "drag and drop".

| |
|---|
| Safety |
| Optical design |
| Ergonomy |
| Fun aspect |
| Performance |
| Other |

9 [Seiten-ID: 446892] [L]

Produktentwicklung 3

### *4.3 Finally let's talk about the use of methods for product development.*

**Which methods do you use for product development?**

#### Finding ideas

**Use of research methods (analysis):**

- Motion analysis
- Performance diagnostics
- Other: (Please specify!)
- Interview (or questionnaire)
- Anthropomentry analysis: measures of body segments
- Other: (Please specify!)
- Measurement of loads (forces/pressure, etc.)
- Modelling and simulation
- Other: (Please specify!)

**Use of methods to support the design process:**

- List of requirements
- Design matrices
- Functional structure
- Brainstorming
- Inquiry (standard parts, solutions available, competitors, etc.)
- Construction/design catalogues
- Structuring schemes (z.B. morphologic box)
- Assessment schemes
- ABC Analysis

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- Other: (Please specify!)
- Other: (Please specify!)
- Other: (Please specify!)

**Use of methods in the development (synthesis):**

- Test
- Other: (Please specify!)
- Construction/design
- Other: (Please specify!)
- Calculation
- Other: (Please specify!)

#### Analysis of requirements

**Use of research methods (analysis):**

- Motion analysis
- Performance diagnostics
- Other: (Please specify!)
- Interview (or questionnaire)
- Anthropomentry analysis: measures of body segments
- Other: (Please specify!)
- Measurement of loads (forces/pressure, etc.)
- Modelling and simulation
- Other: (Please specify!)

**Use of methods that support the design process:**

- List of requirements
- Design matrices
- Functional structure
- Other: (Please specify!)
- Brainstorming
- Inquiry (standard parts, solutions available, competitors, etc.)
- Construction/design catalogues
- Other: (Please specify!)
- Structuring schemes (z.B. morphologic box)
- Assessment schemes
- ABC Analysis
- Other: (Please specify!)

**Use of methods in the development (synthesis):**

- Test
- Other: (Please specify!)
- Construction/design
- Other: (Please specify!)
- Calculation
- Other: (Please specify!)

#### Research and development

**Use of research methods (analysis):**

- Motion analysis
- Performance diagnostics
- Other: (Please specify!)
- Interview (or questionnaire)
- Anthropomentry analysis: measures of body segments
- Other: (Please specify!)
- Measurement of loads (forces/pressure, etc.)
- Modelling and simulation
- Other: (Please specify!)

**Use of methods that support the design process:**

- List of requirements
- Design matrices
- Functional structure
- Other: (Please specify!)
- Brainstorming
- Inquiry (standard parts, solutions available, competitors, etc.)
- Construction/design catalogues
- Other: (Please specify!)
- Structuring schemes (z.B. morphologic box)
- Assessment schemes
- ABC Analysis
- Other: (Please specify!)

**Use of methods in the development (synthesis):**

- Test
- Other: (Please specify!)
- Construction/desing
- Other: (Please specify!)
- Calculation
- Other: (Please specify!)

#### Product test

Analysis by tests etc. aiming at a proof of functionality of the product.

**Use of research methods (analysis):**

- Motion analysis
- Performance diagnostics
- Other: (Please specify!)
- Interview (or questionnaire)
- Anthropomentry analysis: measures of body segments
- Other: (Please specify!)
- Measurement of loads (forces/pressure, etc.)
- Modelling and simulation
- Other: (Please specify!)

**Use of methods that support the design process:**

- List of requirements
- Design matrices
- Functional structure
- Brainstorming
- Inquiry (standard parts, solutions available, competitors, etc.)
- Construction/design catalogues
- Structuring schemes (z.B. morphologic box)
- Assessment schemes
- ABC Analysis

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| | | |
|---|---|---|
| ☐ Other: (Please specify!) | ☐ Other: (Please specify!) | ☐ Other: (Please specify!) |

**Use of methods in the development (synthesis):**

| | | |
|---|---|---|
| ☐ Test | ☐ Construction/desing | ☐ Calculation |
| ☐ Other: (Please specify!) | ☐ Other: (Please specify!) | ☐ Other: (Please specify!) |

## Validation

Verification of statements that have been made before about the product in interaction with the user (sportsman), e.g. "the new damping system reduces high frequency vibration about 30%".

**Use of research methods (analysis):**

| | | |
|---|---|---|
| ☐ Motion analysis | ☐ Interview (or questionnaire) | ☐ Measurement of loads (forces/pressure, etc.) |
| ☐ Performance diagnostics | ☐ Anthropomentry analysis: measures of body segments | ☐ Modelling and simulation |
| ☐ Other: (Please specify!) | ☐ Other: (Please specify!) | ☐ Other: (Please specify!) |

**Use of methods that support the design process:**

| | | |
|---|---|---|
| ☐ List of requirements | ☐ Brainstorming | ☐ Structuring schemes (z.B. morphologic box) |
| ☐ Design matrices | ☐ Inquiry (standard parts, solutions available, competitors, etc.) | ☐ Assessment schemes |
| ☐ Functional structure | ☐ Construction/design catalogues | ☐ ABC Analysis |
| ☐ Other: (Please specify!) | ☐ Other: (Please specify!) | ☐ Other: (Please specify!) |

**Use of methods in the development (synthesis):**

| | | |
|---|---|---|
| ☐ Test | ☐ Construction/design | ☐ Calculation |
| ☐ Other: (Please specify!) | ☐ Other: (Please specify!) | ☐ Other: (Please specify!) |

**Would you be interested in guidelines and a competence network for product development of sports equipment?**

(Multiple choice possible!)

☐ Yes, specificly for the analysis of requirements
☐ Yes, specificly for the development
☐ Yes, specificly for research topics
☐ Yes, specificly for product tests
☐ Yes, specificly for (Please specify!)
☐ No

**10 [Seiten-ID: 446893] [L]**

**Mechatronik**

### *4. The last section of the questionnaire is about the use of mechatronic components in your products.*

Mechatronic is regarded as the coaction of mechanical, electronical and information systems in a product (e.g. integrated load sensing in parts, piezo elements for damping of vibrations, etc.).

**Do you apply mechatronic components in your products?**

○ Yes
○ No

**Do you plan to apply mechatronic components in your products?**

○ Yes
○ No

**What can you say about the potential of mechatronic components for your products?**

| | very high | high | low | not existing |
|---|---|---|---|---|
| The potential is... | ○ | ○ | ○ | ○ |

**Please provide reasons for your estimation!**

e.g. from the customer benefit point of view, Marketing, etc.





1. Reason:
2. Reason:
3. Reason:
4. Reason:

**11 [Seiten-ID: 446894] [L]**

**Endseite**

**Thank you very much for completing this survey!**

## 8.2.2 Questionnaire of the survey among sports retailers

The following set of questions was presented to selected sports retailers in interviews. The results served to explore the sports retailers' point of view on important aspects of sports technology design and were compared to the results of the survey among sports technology manufacturers and athletes.

Datum: 13.02.2009
Uhrzeit: 12:00
Interviewer: Maximilian Müller
Protokoll: Maximilian Müller

Interview-Partner:

---

**Einleitung**

- Ich beschäftige mich im Rahmen meiner Dissertation mit den Besonderheiten bei der Entwicklung von Sportausrüstung und fokussiere mich dabei auf die Bereiche Rad und Ski
- Im Vordergrund steht dabei insbesondere die Anforderungsklärung und die Art und Weise, wie diffuse, sehr individuelle, Konstrukte wie Spassempfinden oder Sicherheit für die Produktentwicklung operationalisiert werden können
- Darüber hinaus beschäftige ich mich mit der Einführung von Methoden der Produktentwicklung aus den Ingenieurswissenschaften in die Sportgeräteentwicklung

**Präambel**

- Die Ergebnisse der Befragung dienen ausschließlich der wissenschaftlichen Verwertung in meiner Doktorarbeit
- Falls Sie Fragen aufgrund von Geheimhaltungsvereinbarungen oder internen Regelungen nicht beantworten können so überspringen wir die Frage
- Falls Sie Fragen aufgrund nicht vorhandener Informationen nicht beantworten können, so überspringen wir die Frage ebenfalls

---

**Sportmotivatoren und Zielgruppen**

1. Was sind Ihrer Meinung nach die wichtigsten Motivatoren, die Menschen heute zum Sporttreiben in ihrer Freizeit anregen?
2. Gibt es Ihrer Meinung nach momentan übergeordnete Trends, die man im Freizeitsport beobachten kann?
3. Welche Zielgruppen von Sportlern oder auch aktiven Menschen unterscheiden Sie in Ihren strategischen Überlegungen?
4. Auf welche dieser Zielgruppen legen Sie für XXX in den nächsten 2-3 Jahren besonderes Augenmerk?
5. Was zeichnet diese Zielgruppen gegenüber anderen Zielgruppen aus?

**Strategische Produktplanung**

6. Was sind aus Ihrer Sicht besondere Merkmale von Sportausrüstung im Vergleich zu anderen Produkten wie PkWs, Konsumer-Elektronik oder Haushaltsgeräten?
7. Woher kommen Ihrer Meinung nach Ideen für neue Produkte?
8. Was sind Ihrer Meinung nach limitierende Faktoren bei der Umsetzung von Produktinnovationen? Die Frage bezieht sich auf alle Bereiche der Wertschöpfungskette vom Hersteller über die Händler bis zum Endkunden.
9. Schätzen sie die Produktentwicklungen im Bereich AlpinSki in den letzten 2-3 Jahren hinsichtlich Ihres Neuheitsgrades ein – sind dies eher Optimierungsentwicklungen oder Neuentwicklungen?
10. Können Sie hierfür Beispiele nennen?
11. Haben speziell diese Entwicklungen aus Ihrer Sicht auch wirklich zu einem verstärkten Kaufanreiz geführt?
12. Was sind Ihrer Meinung nach produktbezogene Defizite, mit denen die Fahrradbranche derzeit zu kämpfen hat?

**Produkteigenschaften**

Unter Produkteigenschaften verstehe ich Aspekte wie Funktion, Design, Sicherheit, Ergonomie, usw. auf die ich im folgenden auch noch genauer eingehen werde.

13. Gibt es Produkteigenschaften die Sie hinsichtlich ihrer Wichtigkeit anders beurteilen würden als es Ihre Kunden tun?
14. Gibt es hinsichtlich der Produkteigenschaften Entwicklungen die Sie kritisch beobachten?
15. Gibt es für solche Diskussionspunkte Austauschorgane zwischen Herstellern und Händlern?
16. Wie beurteilen Sie als Händler die Wichtigkeit von Betriebssicherheit bei AlpinSki?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

17. Wie beurteilen Ihre Kunden diesen Aspekt?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

18. Wie entwickelt sich die Nachfrage in den letzten 3 Jahren nach zusätzlichen Produkten zur Steigerung der persönlichen Sicherheit beim AlpinSki fahren? Ich denke dabei an Produkte wie Rückenprotektoren, Helme, etc.

19. Was sind Ihrer Meinung nach Gründe hierfür?

20. Wie beurteilen Sie die Wichtigkeit von Design im Sinne von Produktgestalt (also z.B. besondere Formgebung, Farben, Muster, etc.) bei AlpinSki?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

21. Wie beurteilen Ihre Kunden diesen Aspekt?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

22. Wie beurteilen Sie die Wichtigkeit von Ergonomie (also z.B. individuelle Einstellmöglichkeiten) bei AlpinSki?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

23. Wie beurteilen Ihre Kunden diesen Aspekt?

24. Wie wichtig ist für Ihre Kunden der Spaßfaktor bei der Nutzung von AlpinSki? Damit ist z.B. ein besonders dynamisches Fahrverhalten gemeint.

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

25. Wie beurteilen Sie die Wichtigkeit der Produkt-Performance (also z.B. Gewicht und Steifigkeit des Rahmens) bei AlpinSki?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

26. Wie beurteilen Ihre Kunden diesen Aspekt?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

27. Wie beurteilen Sie die Wichtigkeit der einwandfreien Produktfunktion bei AlpinSki?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

28. Wie beurteilen Ihre Kunden diesen Aspekt?

| ☐ | ☐ | ☐ | ☐ |
|---|---|---|---|
| sehr wichtig | wichtig | nicht wichtig | nicht relevant |

29. Wie entwickelte sich das Preisbewusstsein der Kunden im Bereich AlpinSki in den letzten 2-3 Jahren?

30. Gibt es noch weitere Produkteigenschaften die Ihrer Meinung nach eine Rolle beim Kauf von AlpinSki spielen?

31. Wie bewerten Sie deren Wichtigkeit?

**Modellvielfalt und Individualisierung**

32. Wie hat sich die Modellvielfalt im Bereichen AlpinSki in den letzten 10 Jahren entwickelt?

33. Von welcher Seite werden diese Entwicklungen Ihrer Meinung nach getrieben: Hersteller, Kunden, Händler oder vielleicht sogar noch durch weitere Einflüsse?

34. Wohin geht Ihrer Meinung nach die Entwicklung der Modellvielfalt von AlpinSki in den nächsten 2-3 Jahren ?

35. Was sind Ihrer Meinung nach die Gründe für diese Entwicklung?

36. Wie entwickelt sich nach Ihrer Kenntnis die Nachfrage nach ergonomisch einstellbaren oder sogar individuell angepassten Produkten im Bereich Moutain-Bike?

37. Wie entwickelt sich Ihrer Einschätzung nach die Nachfrage nach anderweitig individualisierbaren Produkten – etwa hinsichtlich der Auswahlmöglichkeiten von technischen Ausstattungsmerkmalen?

38. Gibt es Produkteigenschaften die davon besonders betroffen sind?

**Mechatronik im Sport**

Unter Mechatronik versteht man das Zusammenwirken von mechanischen, elektronischen und informationstechnischen Systemen in einem Produkt. Etwas weiter verbreitete Beispiele aus dem Sportbereich sind Herzfrequenzmesser und Fahrradcomputer.
Hierunter würden auch weitergehende Funktionalitäten zur Bewegungsanalyse oder Belastungsmessung fallen.

39. Im Unterschied zu anderen Branchen wie der Automobilbranche spielten mechatronische Komponenten bei Sportausrüstung bisher eine geringe Rolle. Was sind Ihrer Meinung nach Gründe für diese Zurückhaltung?

40. Was sind in diesem Zusammenhang aus Ihrer Sicht Funktionen oder Anwendungen, die der Kunde als nützlich empfinden könnte?

41. Wie schätzen Sie darauf aufbauend das Potential für elektronische Komponenten im Sport ein?

42. Wie müsste aus Ihrer Sicht die kurzfristige preispolitische Vermarktung solcher Produkte erfolgen? Sollte die Tendenz eher zu einfachen Low-Cost Anwendungen gehen oder eher mit hochwertigen Produkten das obere Preissegment besetzt werden?

43. Welche technischen Voraussetzungen sollten Produkte mit mechatronischen Komponenten aus Ihrer Sicht erfüllen?

44. Wie eignet Sich Ihrer Meinung nach das Mobiltelefon für die Datenverarbeitung- und darstellung im Sport?

45. Welche besonderen Eigenschaften wären für ein Sport-Handy Ihrer Meinung nach wichtig?

**Allgemeine Angaben zum Unternehmen**

46. Wieviele Mitarbeiter beschäftigt Ihr Unternehmen?

47. Wie hoch war der weltweite Umsatz Ihres Unternehmens im Jahr 2007?

48. In welchem Bereich wird sich XXX in den nächsten 2-3 Jahren am meisten verändern?

49. Eine provokative Frage: 100% bis 140% Händlermarge – ist das genug zum Leben für Sie?

50. Wie sieht der Sportfachhandel in 10 Jahren aus?

51. Was sind aus Ihrer Sicht wichtige Stellgrößen, die die Entwicklung des Sportfachhandels beeinflussen werden?

### 8.2.3 Questionnaire of the survey among athletes

The following set of questions was presented to athletes (in the sense of people predominantly active in leisure sports) in an online survey. The results served to explore the athletes' point of view on important aspects of sports technology design and were compared to the results of the survey among sports technology manufacturers and sports retailers.

Optionen

| | |
|---|---|
| Sprache | Deutsch |

Sprache wählen

**Anzeige-Optionen ändern**

**Info**: Hier können Sie optional die Anzeige-Optionen verändern.

Anzeige-Optionen einstellen:

- ☐ Filter anzeigen
- ☐ Pretest-Kommentare anzeigen
- ☐ Todos anzeigen
- ☐ Trigger anzeigen
- ☐ Plausichecks anzeigen
- ☐ Randomisierung abschalten

Aktion ausführen

Informationen zur Umfrage Online Kundenbefragung „Digital Skiing Coach" - Stephan Hinz

| | |
|---|---|
| Umfrage-Nr. | 100068 |
| Autor | Stephan Hinz |
| Mitarbeiter | Stephan Hinz |
| Start | 2008-06-29 00:00:00 |
| Ende | 2008-08-13 00:00:00 |

Fragebogen

**3 [Seiten-ID: 585572] [L]**

**Anfang 1**

Kundenbefragung „Digital Skiing Coach"

**Herzlich Willkommen zur Umfrage!**

Vorab schon einmal vielen Dank für die Zeit und Mühe für das Mitwirken an der Umfrage.

Die Umfrage ist Teil einer Diplomarbeit an der Technischen Universität München, Fachgebiet für Sportgeräte und Materialien.

Hinterfragt und überprüft werden in dieser Umfrage viele Bereiche über den Digital Skiing Coach, welches ein System ist, das dem Skifahrer über ein akustisches Signal eine direkte Rückmeldung über seine Fahrtechnik gibt.
Das Ziel ist es mit der Umfrage eine bestmögliche Strategie für die Markteinführung des Digital Skiing Coach zu entwickeln.

**Kurz noch ein paar Hinweise zu der folgenden Befragung:**
- Bitte füllen Sie den Fragebogen vollständig aus.
- Falls Mehrfachnennungen möglich sind, wird darauf gesondert hingewiesen.
- Falls Ihre Antwort nicht gegeben ist, haben Sie bei manchen Fragen die Möglichkeit im untersten Textfeld Ihre Antwort einzugeben.
- Die Bearbeitungszeit des Fragebogens dauert ca. 15 Minuten

**Ihre Angaben werden selbstverständlich streng vertraulich behandelt und nicht an Dritte weitergegeben.**

Als kleines Dankeschön werden wir unter den Teilnehmern dieser Befragung eine **Halti Outdoor Jacke "Thoran 350"** im Wert von 179 EURO verlosen.

**5 [Seiten-ID: 585590] [L]**

Frageseite 1 Fr. 1

**Inwieweit stimmen Sie den folgenden Aussagen auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Die Produktidee finde ich interessant | ○ | ○ | ○ | ○ |
| Ich kann mir vorstellen ein solches Produkt zu testen | ○ | ○ | ○ | ○ |
| Es wäre für mich interessant, Parameter über meine Fahrtechnik zu erfahren | ○ | ○ | ○ | ○ |
| Ein solches Produkt fehlt bisher auf dem Sportmarkt | ○ | ○ | ○ | ○ |
| Das Produkt würde mein Interesse wecken | ○ | ○ | ○ | ○ |
| Dieses Produkt halte ich für innovativ | ○ | ○ | ○ | ○ |

**6 [Seiten-ID: 585615] [L]**

Frageseite 2 Fr. 2+3

**Inwieweit stimmen Sie den folgenden Aussagen auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Kabellose Datenübertragung via Bluetooth auf ein Mobiltelefon finde ich gut | ○ | ○ | ○ | ○ |
| Eine Datenauswertung an einem Computer nach dem Skifahren finde ich interessant | ○ | ○ | ○ | ○ |
| Ich nutze häufig die Bluetooth Technik in meinem Handy | ○ | ○ | ○ | ○ |

**Inwieweit stimmen Sie den folgenden Aussagen auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**
Bitte stellen Sie sich vor, dass Sie den Digital Skiing Coach beim Skifahren nutzen und beantworten dann anschließend bitte die Fragen.

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Sicherheit ist für mich ein wichtiger Faktor im Sport | ○ | ○ | ○ | ○ |
| Elektronische Hilfsmittel vermitteln mir mehr Sicherheit beim Sport | ○ | ○ | ○ | ○ |
| Der Digital Skiing Coach würde mir beim Skifahren mehr Sicherheit geben | ○ | ○ | ○ | ○ |
| Mit dem Digital Skiing Coach würde ich mich trauen schwierigere Abfahrten zu fahren | ○ | ○ | ○ | ○ |
| Mit dem Digital Skiing Coach würde ich mehr Risiko eingehen | ○ | ○ | ○ | ○ |
| Die Sicherheit meiner Sportausrüstung ist mir wichtig | ○ | ○ | ○ | ○ |
| Ich bewege mich beim Sport immer in für mich sicheren Bereichen | ○ | ○ | ○ | ○ |

**7 [Seiten-ID: 585622] [L]**

Frageseite 3 Fr. 4

**Inwieweit stimmen Sie den folgenden Aussagen auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**
Die Aussagen sind auf Sportprodukte bezogen.

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Der Preis spielt beim Kauf eines Produktes eine entscheidende Rolle | ○ | ○ | ○ | ○ |
| Ich gebe für neue und innovative Produkte mehr Geld aus | ○ | ○ | ○ | ○ |
| Ein gutes Preis – Leistungsverhältnis ist wichtig | ○ | ○ | ○ | ○ |
| Ein günstiger Preis ist ein Grund für den Kauf eines Produkts | ○ | ○ | ○ | ○ |
| Die Marke des Produktes ist wichtig bei meinem Kauf | ○ | ○ | ○ | ○ |
| Ein gutes Image des Produktes ist wichtiger als der Preis | ○ | ○ | ○ | ○ |
| Die Qualität des Produktes ist mir wichtiger als der Preis | ○ | ○ | ○ | ○ |
| Die Funktionalität des Produktes ist mir wichtiger als der Preis | ○ | ○ | ○ | ○ |

**8 [Seiten-ID: 585624] [L]**

Frageseite 4 Fr. 5+6

**Wo würden Sie sich über den Digital Skiing Coach informieren?**
(Mehrfachnennungen möglich)

- ☐ Internet / Online
- ☐ Testveranstaltungen
- ☐ In Sportfachgeschäften

☐ In Skischulen
☐ Fachzeitschriften (Bsp. Ski Magazin)
☐ Auf Skirennen des FIS Weltcup

Sonstiges

**Welche Ski - und Bergsportzeitschriften lesen Sie?**
(Mehrfachnennungen möglich)

☐ DSV Aktiv Ski & Sportmagazin (Deutscher Ski Verband)
☐ DAV Magazin (Deutscher Alpenverein)
☐ Ski Magazin
☐ Allmountain Magazin
☐ Alpenjournal
☐ Snow Magazin
☐ Fit for Fun
☐ Men´s Health
☐ Shape
☐ Sonstiges

**9 [Seiten-ID: 585658] [L]**

Frageseite 5 Fr. 7+8+15+16

**Wo würden Sie den Digital Skiing Coach kaufen?**
(Mehrfachnennungen möglich)

☐ Internet / Online
☐ Sportfachgeschäft
☐ Kaufhaus
☐ Messe
☐ im Skigebiet bei Skischulen

Sonstiges

**Könnten Sie sich vorstellen den Digital Skiing Coach zu mieten?**

☐ ja
☐ nein

**Inwieweit stimmen Sie der folgenden Aussage auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Ich könnte mir vorstellen, den Digital Skiing Coach zu kaufen | ○ | ○ | ○ | ○ |

**Zu welchem Preis würden Sie den Digital Skiing Coach kaufen?**

in EURO

**10 [Seiten-ID: 585662] [L]**

Frageseite 6 Fr. 9

**In welchen Sportarten und Bereichen könnten Sie sich den Einsatz des Digital Skiing Coachs noch vorstellen?**
(Mehrfachnennungen möglich)

☐ Snowboarden
☐ Langlauf
☐ Jogging
☐ Eislaufen
☐ Eishockey
☐ Radfahren
☐ bei Rehabilitationsmaßnahmen

Sonstiges

**11 [Seiten-ID: 585686] [L]**

Frageseite 7 Fr. 10+11+12

**Welche der folgenden Hilfsmittel verwenden Sie beim Sport?**
(Mehrfachnennungen möglich)

☐ Herzfrequenzmesser (Pulsuhr)
☐ GPS Systeme
☐ Beheizbare Einlegesohlen (z.B. für Skifahren)

- [ ] In Textilien integrierte Musikkomponenten (MP3 Systeme)

Sonstiges

**Welche Funktionen würden Sie sich zusätzlich bei dem Digital Skiing Coach wünschen?**
(Mehrfachnennungen möglich)

- [ ] Messung der Herzfrequenz
- [ ] Messung der Geschwindigkeit
- [ ] Messung der verbrauchten Kalorien
- [ ] Integrierte Musikkomponenten (MP3 Systeme)
- [ ] Sonstiges

**12 [Seiten-ID: 585689] [L]**

Frageseite 8 Fr. 13

**Inwieweit stimmen Sie den folgenden Aussagen auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Systeme, die mir Feedback über die Bewegungsanalyse im Sinne der Körperbewegung geben, finde ich gut | ○ | ○ | ○ | ○ |
| Systeme, die Geschwindigkeiten messen, würden mir zusätzlichen Nutzen bieten | ○ | ○ | ○ | ○ |
| Systeme, die Vitalparameter (Herzfrequenz) messen, würden mir zusätzlichen Nutzen bieten | ○ | ○ | ○ | ○ |
| Systeme, die verbrauchten Kalorien messen, würden mir zusätzlichen Nutzen bieten | ○ | ○ | ○ | ○ |
| Systeme sollten direktes Feedback über die Technik liefern | ○ | ○ | ○ | ○ |
| Systeme sollten direktes Feedback über die Bewegungsausführung liefern | ○ | ○ | ○ | ○ |
| Systeme sollten direktes Feedback über die Vitalparameter liefern | ○ | ○ | ○ | ○ |

**13 [Seiten-ID: 585691] [L]**

Frageseite 9 Fr. 14

**Auf was legen Sie beim Kauf neuer Produkte besonders Wert?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Qualität | ○ | ○ | ○ | ○ |
| Niedriger Preis | ○ | ○ | ○ | ○ |
| Preis - Leistungsverhältnis | ○ | ○ | ○ | ○ |
| Marke | ○ | ○ | ○ | ○ |
| Design | ○ | ○ | ○ | ○ |
| Service / Beratung | ○ | ○ | ○ | ○ |
| Garantie | ○ | ○ | ○ | ○ |
| Neueste Technik | ○ | ○ | ○ | ○ |
| Neueste Materialien | ○ | ○ | ○ | ○ |
| Funktionalität | ○ | ○ | ○ | ○ |
| Gutes Image der Marke | ○ | ○ | ○ | ○ |
| Lange Produkthaltbarkeit | ○ | ○ | ○ | ○ |
| Meinung von Freunden und Bekannten | ○ | ○ | ○ | ○ |
| Sonstiges | ○ | ○ | ○ | ○ |

**14 [Seiten-ID: 585700] [L]**

Frageseite 10 Fr. 17+18

**Was ist Ihre Motivation Sport zu treiben?**
(Mehrfachnennungen möglich)

- [ ] Körperliche Leistungsfähigkeit verbessern (konditionell)
- [ ] Wohlfühlen
- [ ] Ausgleich zur Arbeit (Stressabbau)
- [ ] Spaß an der Bewegung
- [ ] Stärkung des Immunsystems
- [ ] Diät / eine gute Figur zu haben
- [ ] Freunde treffen

- [ ] An seine Grenzen gehen
- [ ] Neue Leute kennen lernen

Sonstiges

**Was sind aus Ihrer Sicht besondere Merkmale von Sportprodukten im Vergleich zu anderen Produkten, wie Konsumer - Elektronik (MP3-Player) oder Haushaltsprodukten?**
Bitte tragen Sie spontan 3 Stichwörter in die 3 Zeilen ein.

**15 [Seiten-ID: 585703] [L]**

Frageseite 11 Fr. 19+20

**Wie wichtig sind Ihnen die folgenden Aussagen auf einer Skala 1 (sehr wichtig) bis 4 (nicht relevant) zu?**
Wie wichtig ist Ihnen.....

| | sehr wichtig | wichtig | nicht wichtig | nicht relevant |
|---|---|---|---|---|
| das Design bei Sportprodukten? | ○ | ○ | ○ | ○ |
| die Ergonomie bei Sportprodukten? | ○ | ○ | ○ | ○ |
| eine lange Lebensdauer bei Sportprodukten? | ○ | ○ | ○ | ○ |
| eine einwandfreie Funktion Ihres Sportprodukts? | ○ | ○ | ○ | ○ |
| die Verwendung von hochwertigen Materialien bei Sportprodukten? | ○ | ○ | ○ | ○ |
| eine Sportausrüstung, die die persönliche Sicherheit erhöht? | ○ | ○ | ○ | ○ |
| der Spaßfaktor bei Sportprodukten? | ○ | ○ | ○ | ○ |
| die Produkt – Performance (z.B. Gewicht, Steifigkeit, Flexibilität etc.) bei Sportprodukten? | ○ | ○ | ○ | ○ |
| eine einwandfreie Produktfunktion bei Sportprodukten? | ○ | ○ | ○ | ○ |

**Gibt es beim Kauf von Sportprodukten noch weitere Eigenschaften, die Ihrer Meinung nach eine Rolle spielen?**

- ○ Nein
- ○ Ja, dann nennen Sie bitte die Eigenschaften

**16 [Seiten-ID: 585741] [L]**

Frageseite 12 Fr. 21

**Wie wichtig sind Ihnen die folgenden Aussagen auf einer Skala 1 (sehr wichtig) bis 4 (nicht relevant) zu?**

| | sehr wichtig | wichtig | nicht wichtig | nicht relevant |
|---|---|---|---|---|
| Wie wichtig ist es Ihnen eine große Auswahlmöglichkeit an verschiedenen Modellen eines Sportprodukts zu haben? | ○ | ○ | ○ | ○ |
| Wie wichtig sind Ihnen ergonomische Produkte? | ○ | ○ | ○ | ○ |
| Wie wichtig sind Ihnen – hinsichtlich der Auswahlmöglichkeiten von technischen Ausstattungsmerkmalen – individualisierbare Produkte? | ○ | ○ | ○ | ○ |

**17 [Seiten-ID: 585746] [L]**

Frageseite 13 Fr. 22+23+24

**Welche technischen Voraussetzungen sollten Produkte mit mechatronischen Komponenten aus Ihrer Sicht erfüllen?**
(Mehrfachnennungen möglich)

- [ ] Lange Batterielaufzeit
- [ ] Einfache Bedienung
- [ ] Darf bei der Bewegungsausführung nicht stören
- [ ] Geringes Gewicht
- [ ] Wetterfest
- [ ] Soll beweglich sein (flexible Materialien)
- [ ] Sonstiges

**Inwieweit stimmen Sie der folgenden Aussage auf einer Skala 1 (stimme voll zu) bis 4 (stimme gar nicht zu) zu?**

| | stimme voll zu | stimme zu | stimme nicht zu | stimme gar nicht zu |
|---|---|---|---|---|
| Das Mobiltelefon eignet sich gut für Datenverarbeitung - und Darstellung im Sport | ○ | ○ | ○ | ○ |

**Welche besonderen Eigenschaften wäre für ein Sport - Handy Ihrer Meinung nach wichtig?**
(Mehrfachnennungen möglich)

- [ ] Robustheit
- [ ] Wasserdicht
- [ ] Stoßfestes Display

- [ ] Lang haltender Akku
- [ ] Große Tasten
- [ ] Großes Display
- [ ] Verschiedene Schnittstellen (Bluetooth, Infrarot, W-Lan etc.)
- [ ] Sonstiges

**18 [Seiten-ID: 597249] [L]**

Frageseite 14 Fr. 25+26+27

**Wie viel Geld geben Sie durchschnittlich im Jahr für Sportartikel aus?**

in EURO

**Wie viel Geld geben Sie durchschnittlich im Jahr für Skiprodukte aus?**

in EURO

**Wie viele Skitage haben Sie durchschnittlich in einem Jahr?**

In Tagen

**19 [Seiten-ID: 585767] [L]**

Demographie

**Bitte füllen Sie nun noch einige Fragen zu Ihrer Person aus.**
**Ihr Geschlecht**

- ◯ weiblich
- ◯ männlich

**Ihr Alter**

in Jahren

**Was ist Ihre höchste Schulbildung?**

- ◯ Hauptschule
- ◯ Mittlere Reife
- ◯ Abitur
- ◯ Fachhochschule ohne Abschluss
- ◯ Fachhochschule mit Abschluss
- ◯ Universität ohne Abschluss
- ◯ Universität mit Abschluss
- ◯ Promotion

**Welcher Tätigkeit gehen Sie aktuell nach?**

- ◯ Schüler
- ◯ Student
- ◯ Auszubildender (Azubi)
- ◯ angestellter Mitarbeiter
- ◯ leitender Mitarbeiter
- ◯ Geschäftsführer
- ◯ selbstständiger Unternehmer

**Haben Sie Kinder?**

- ◯ ja
- ◯ nein

**Wie ist Ihr aktueller Familienstand?**

- ◯ ledig
- ◯ ledig in einer Partnerschaft lebend
- ◯ verheiratet
- ◯ geschieden
- ◯ verwitwet

**20 [Seiten-ID: 585775] [L]**

Dankeschön

**Vielen Dank für Ihre Mithilfe!**

Wenn Sie an der Verlosung der Halti Outdoor Jacke teilnehmen möchten, dann tragen Sie bitte in dem nachfolgenden Textfeld Ihre E-Mail Adresse ein.

## 8.3 Additional materials on the quantification of fun experience

### 8.3.1 Calculation of typical speeds and accelerations in ski turns

For reasons of comparability, the study concerning the quantification of fun was conducted under conditions which are comparable to typical leisure skiing. The following assumpations and results were drawn for this calculation.

| | | |
|---|---|---|
| mm (kg) | 82.4 | mean mass of male skiers |
| mf (kg) | 67.5 | mean mass of female skiers |
| r (m) | 15 | turn radius |

| | | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|
| v [km/h] | v [m/s] | a(r15) [m/s²] | a(r15) [g] | a20 [m/s²] | a(r20) [g] | a25 [m/s²] |
| 20 | 5.56 | 2.06 | 0.21 | 1.54 | 0.16 | 1.23 |
| 30 | 8.33 | 4.63 | 0.47 | 3.47 | 0.35 | 2.78 |
| 40 | 11.11 | 8.23 | 0.84 | 6.17 | 0.63 | 4.94 |
| 50 | 13.89 | 12.86 | 1.31 | 9.65 | 0.98 | 7.72 |

| v [km/h] | a(r=15m) | a(r=20m) | a(r=25m) | a(r=30m) | a(r=35m) | a(r=40m) |
|---|---|---|---|---|---|---|
| 20 | 0.21 | 0.16 | 0.13 | 0.10 | 0.09 | 0.08 |
| 30 | 0.47 | 0.35 | 0.28 | 0.24 | 0.20 | 0.18 |
| 40 | 0.84 | 0.63 | 0.50 | 0.42 | 0.36 | 0.31 |
| 50 | 1.31 | 0.98 | 0.79 | 0.66 | 0.56 | 0.49 |

### 8.3.2 Questionnaire for the quantification of fun experience

The following questionnaire was presented to the participants of the study that served to quantify fun experience as a sensation which can be aroused by lateral acceleration during sport activity. The items were collected from various articles and from the results of a brainstorming (for detailed information see Bauer, 2008).

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# Fragebogen

Datum:_________________

Name:_________________________________________

Alter: _________________

Auf den nachfolgenden Seiten werden Sie zu Ihren Eindrücken während der Tandemfahrt befragt. Alle Angaben werden anschließend und für jegliche Veröffentlichung anonymisiert.

Die Bearbeitung des Fragebogens nimmt etwa 30 Minuten in Anspruch. Bitte beantworten Sie alle Fragen. Bitte beantworten Sie die Fragen in der Reihenfolge, in der sie auftreten. Zögern Sie nicht nachzufragen falls Ihnen eine Frage unklar erscheint!

Herzlichen Dank für Ihre Teilnahme !!!

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Falls keine anderen Antwortenmöglichkeiten vorgegeben sind können sie sich bei den nächsten Fragen zwischen oberen Antworten entscheiden entscheiden.

| **Im ersten Teil des Fragebogens stellen wir Ihnen einige Fragen zu Ihren Empfindungen während der Tandemfahrt.** | | | | |
|---|---|---|---|---|
| 1. Hatten Sie das Gefühl, dass sich die Kurvenbeschleunigung während der Fahrt veränderte? | Ja | | Nein | |
| Die folgenden Fragen sind nur zu beantworten, wenn Sie bei der vorhergehenden Frage mit „ja" geantwortet haben (bei *nein* weiter Frage 2)! | | | | |
| 1.1 Hatten Sie das Gefühl dass sich die Kurvenbeschleunigung während der Fahrt erhöhte? | 1 | 2 | 3 | 4 |
| 4. Fühlten Sie sich in der Kurve wie in einer Art freiem Fall? | 1 | 2 | 3 | 4 |
| 5. Hatten Sie während der Fahrt dass Ihr Körper vom Rad gezogen wird | 1 | 2 | 3 | 4 |
| 6. Mußten Sie sich während der Fahrt an den Lenke klammern? | 1 | 2 | 3 | 4 |
| 7. Hatten Sie während der Fahrt das Gefühl dass Ih Körper in die Kurve gedrückt wird? | 1 | 2 | 3 | 4 |
| 8.Fühlte sich die Fahrt an wie eine Art Flugzeuglandung? | 1 | 2 | 3 | 4 |
| 9. Hatten Sie während der Fahrt das Gefühl als würden Si in einem Lift fahren? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 10. Hatten Sie während der Fahrt das Gefühl als würden Si aus der Kurve gehoben? | 1 | 2 | 3 | 4 |
| 11. Hatten Sie nach der Fahrt wackelige Beine? | 1 | 2 | 3 | 4 |
| 11.1Verstärkte sich die Herausforderung während der Fahrt? | 1 | 2 | 3 | 4 |
| 9. Hatten Sie während der Fahrt das Gefühl als würden Si in einem Lift fahren? | 1 | 2 | 3 | 4 |
| Bitte treffen Sie die Aussagen zu Ihren Empfindungen hier in der Reihenfolge der Nennung in der vorhergehenden Frage! | | | | |
| 13.Machte Ihnen die Fahrt Spaß? | 1 | 2 | 3 | 4 |
| 14. Machte die Fahrt Spaß weil man sich selbst bewegen mußte? | 1 | 2 | 3 | 4 |
| 15.Hat Ihnen die Beschleunigung in den Kurven Spaß gemacht? | 1 | 2 | 3 | 4 |
| 16.Machten Ihnen die Kurvenfahrten mehr Spaß als die geraden Stücke? | 1 | 2 | 3 | 4 |
| 17.Machten Ihnen die geraden Stücke mehr Spaß als die Kurvenfahrten? | 1 | 2 | 3 | 4 |
| 18. Empfanden Sie Nervenkitzel? | 1 | 2 | 3 | 4 |
| 19.Konnten Sie in die Beschleunigung eintauchen? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 20.Konnten Sie während der Fahrt abschalten? | 1 | 2 | 3 | 4 |
| 21.Empfanden Sie das Fahren mit verbundenen Augen als angenehm? | 1 | 2 | 3 | 4 |
| 22.Empfanden Sie das Fahren mit verbundenen Augen als unangenehm? | 1 | 2 | 3 | 4 |
| 23. Hatten Sie das Gefühl, daß sich bestimmte Empfindungen durch die verbundenen Augen während der Fahrt intensivierten? | ja | | nein | |
| Die folgende Frage ist nur zu beantworten, wenn Sie bei der vorhergehenden Frage mit „ja" geantwortet haben (bei *nein* weiter Frage 2)! | | | | |
| 23.1 Welche Empfindungen verstärkten sich durch die verbundenen Augen?<br>1____________________<br>2____________________<br>3____________________ | | | | |
| 24.Intensivierten sich durch das blinde Fahren bestimmte Sinne? | 1 | 2 | 3 | 4 |
| hören | 1 | 2 | 3 | 4 |
| schmecken | 1 | 2 | 3 | 4 |
| riechen | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 25. Konnten Sie durch das blinde Fahren bestimmte Körperregionen besser spüren? | ja | | nein | |
| Die folgende Frage ist nur zu beantworten, wenn Sie bei der vorhergehenden Frage mit „ja" geantwortet haben (bei *nein* weiter Frage 2)! | | | | |
| 25.1Welche Körperregionen spürten Sie durch das blinde Fahren besser?<br>1________________<br>2________________<br>3________________ | | | | |
| 26.Machte Ihnen das blinde Fahren Spaß? | 1 | 2 | 3 | 4 |
| 27.Beeinträchtigte das Blinde fahren den Spaß an der Fahrt? | 1 | 2 | 3 | 4 |
| 27.1Verstärkte das Blinde fahren den Spaß an der Fahrt? | 1 | 2 | 3 | 4 |
| 28.War Tandem Fahren für Sie ein neues Bewegungsgefühl im Bezug auf den Gleichgewichtssinn? | 1 | 2 | 3 | 4 |
| 29.War Tandem Fahren für Sie ein neues Bewegungsgefühl im Bezug auf die Tretbewegung? | 1 | 2 | 3 | 4 |
| 30.Fühlten Sie sich während der Tandemfahrt unwohl? | 1 | 2 | 3 | 4 |
| 31.Wurde Ihr Befinden zum Ende der Fahrt schlechter? | 1 | 2 | 3 | 4 |

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|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 32.War die Blindheit der Grund für Ihr Unwohlsein? | 1 | 2 | 3 | 4 |
| 33.Hatten Sie das Gefühl, daß der Fahrer die Fahrt beherrscht hat? | 1 | 2 | 3 | 4 |
| 34.Hat dieses Empfinden den Spaß an der Fahrt beeinträchtigt? | 1 | 2 | 3 | 4 |
| 35.Hat dieses Empfinden den Spaß an der Fahrt verstärkt? | 1 | 2 | 3 | 4 |
| **Nun möchten wir Ihnen noch einige Fragen zu Ihrem Befinden unmittelbar nach der Fahrt stellen.** | | | | |
| 36.Empfanden Sie nach der Fahrt ein beschwingtes Gefühl? | 1 | 2 | 3 | 4 |
| 36.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 36.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 36.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 37.Fanden Sie die Fahrt belebend? | 1 | 2 | 3 | 4 |
| 37.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 37.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 37.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 38.War die Fahrt für Sie berauschend? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 38.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 38.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 38.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 39.War die Fahrt erfrischend? | 1 | 2 | 3 | 4 |
| 39.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 39.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| .3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 40.Waren sie nach der Fahrt euphorisch? | 1 | 2 | 3 | 4 |
| 40.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 40.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 40.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 41.Fühlten Sie sich nach der Fahrt lebendig? | 1 | 2 | 3 | 4 |
| 41.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 41.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 41.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 42.Fühlten Sie sich nach der Fahrt stimuliert? | 1 | 2 | 3 | 4 |
| 42.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 42.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 42.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 43.Fühlten Sie sich nach der Fahrt voller Energie? | Ei-nige sec 1 | Ei-nige min 2 | ½ h 3 | Mehr als ½ h 4 |
| 43.1Können Sie einschätzen wie lange dieses Gefühl anhält? | s 1 | 2 | 3 | 4 |
| 43.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 43.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 44.Fühlten Sie sich nach der Fahrt positiv gestimmt? | 1 | 2 | 3 | 4 |
| 44.1Können Sie einschätzen wie lange dieses Gefühl anhält? | Ei-nige sec 1 | Ei-nige min 2 | ½ h 3 | Mehr als ½ h 4 |
| 44.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 44.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 45.Fühlten Sie sich nach der Fahrt wie nach einer Adrenalinausschüttung? | 1 | 2 | 3 | 4 |
| 45.1Können Sie einschätzen wie lange dieses Gefühl anhält? | 1 | 2 | 3 | 4 |
| 45.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 45.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 46.Fühlten Sie sich nach der Fahrt erholt? | 1 | 2 | 3 | 4 |
| 46.1Können Sie einschätzen wie lange dieses Gefühl anhält? | Ei-nige sec 1 | Ei-nige min 2 | ½ h 3 | Mehr als ½ h 4 |
| 46.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 46.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 47.Fühlten Sie sich nach der Fahrt leicht? | 1 | 2 | 3 | 4 |
| 47.1Können Sie einschätzen wie lange dieses Gefühl anhält | 1 | 2 | 3 | 4 |
| 47.2Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 47.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| 48.Fühlten Sie sich nach der Fahrt wie unter Strom? | 1 | 2 | 3 | 4 |

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| | | | | |
|---|---|---|---|---|
| 48.1Können Sie einschätzen wie lange dieses Gefühl anhält? | Ei-nige sec 1 | Ei-nige min 2 | ½ h 3 | Mehr als ½ h 4 |
| 48.2 Hatte die oben beschriebene Empfindung etwas mit den verbundenen Augen während der Fahrt zu tun? | 1 | 2 | 3 | 4 |
| 48.3Haben Sie dieses Gefühl immer beim Sporttreiben? | 1 | 2 | 3 | 4 |
| **Im Folgenden stellen wir Ihnen nun einige Fragen zu Ihren Erfahrungen mit Tandems und Sport mit blinder Bewegungsausführung.** | | | | |
| 49.Sie sind schon einmal Tandem gefahren? | Ja | | Nein | |
| Die folgenden Fragen sind nur zu beantworten, wenn Sie bei der vorhergehenden Frage mit „ja" geantwortet haben (bei *nein* weiter Frage 2 | 1 | 2 | 3 | 4 |
| 49.1 Wie oft fahren Sie Tandem? | einmalige Angelegenheit | einmal im Jahr | einmal pro Monat | Wöchentlich |
| 49.2 Wann sind Sie zum letzten Mal Tandem gefahren? | letzte Woche | letzter Monat | letztes Jahr | länger als ein Jahr her |
| 49.3 Sind Sie als Lenker oder als Beifahrer Tandem gefahren? | Lenker | Beifahrer | Beides | |

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|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 50.Schließen Sie manchmal zu Trainingszwecken beim Sport die Augen? | 1 | 2 | 3 | 4 |
| Die folgende Frage ist nur zu beantworten, wenn Sie bei der vorhergehenden Frage mit „ja“ geantwortet haben (bei *nein* weiter Frage 2)! | | | | |
| 650.1Wie of führen sie solche „blinden“ Übungen durch? | Täg lich | Ein mal in der Woc he | Ein mal im Mon at | We niger als ei mal im Mo nat |
| **Abschließend folgen noch einige Fragen was Ihnen an Ihrem Sport am Besten gefällt und was Sie dazu motiviert Sport zu treiben.** | | | | |
| 51. Was gefällt Ihnen an Ihren (maximal) drei am meisten ausgeübten Sportarten am Besten?<br><br>Sportart:<br>1 2 3<br>________ ________ ________<br>________ ________ ________ | | | | |
| 6.3Empfanden Sie die Herausforderung als angenehm | 1 | 2 | 3 | 4 |
| Bitte treffen Sie zu den folgenden Schlagworten jeweils Aussagen zu allen von Ih genannten Sportarten! | | | | |
| *Geschwindigkeit* | 1 | 2 | 3 | 4 |

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|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| *Beschleunigung (z.B. bei Kurvenfahrten)* | 1 | 2 | 3 | 4 |
| *Nervenkitzel* | 1 | 2 | 3 | 4 |
| *Bewußten eingehen von Risiken* | 1 | 2 | 3 | 4 |
| *Mit Anderen Sport treiben* | 1 | 2 | 3 | 4 |
| *Anforderungen an die Bewegungsfertigkeit* | 1 | 2 | 3 | 4 |
| *Bewegungsfreiheit (unterschiedliche Bewegungsabläufe)* | 1 | 2 | 3 | 4 |
| *Körperliche Leistungsfähigkeit verbessern (konditionell)* | 1 | 2 | 3 | 4 |
| 52.Ich treibe Sport weil ich Spaß an der Bewegung habe. | 1 | 2 | 3 | 4 |
| 53.Ich treibe Sport weil es mir Freude macht mich im Freien zu bewegen. | 1 | 2 | 3 | 4 |
| 54.Ich treibe Sport weil ich mich dann besser entspannen kann. | 1 | 2 | 3 | 4 |
| 55.Ich treibe Sport weil es für mich ein guter körperlicher Ausgleich zur Ausbildung / zur Arbeit ist. | 1 | 2 | 3 | 4 |
| 56.Ich treibe Sport weil ich dabei Alltagsstress abbauen kann. | 1 | 2 | 3 | 4 |
| 57.Ich treibe Sport um mich richtig auszutoben. | 1 | 2 | 3 | 4 |
| 58.Ich treibe Sport weil ich den Nervenkitzel dabei mag. | 1 | 2 | 3 | 4 |

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| 1 = trifft überhaupt nicht zu | 2 = trifft eher nicht zu | 3 = trifft eher zu | 4 = trifft völlig zu |
|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 59.Ich treibe Sport weil ich das Risiko dabei mag. | 1 | 2 | 3 | 4 |
| 60.Ich treibe Sport weil ich mich danach wohl fühle. | 1 | 2 | 3 | 4 |
| 61.Wenn ich Sport treibe werde ich nicht so leicht krank. | 1 | 2 | 3 | 4 |
| 62.Wenn ich Sport treibe schütze ich mich vor Verletzungen. | 1 | 2 | 3 | 4 |
| 63.Ich treibe Sport um mich konditionell fit zu halten. | 1 | 2 | 3 | 4 |
| 64.Ich treibe Sport um eine gute Figur zu haben. | 1 | 2 | 3 | 4 |
| 65.Ich treibe Sport um mich mit Anderen zu messen. | 1 | 2 | 3 | 4 |
| 66.Ich treibe Sport um meine eigenen Leistungsfähigkeit zu verbessern. | 1 | 2 | 3 | 4 |
| 67.Ich treibe Sport um etwas mit anderen Leuten zusammen zu machen. | 1 | 2 | 3 | 4 |
| 68.Ich treibe Sport um neue Leute kennen zu lernen. | 1 | 2 | 3 | 4 |
| 69.Ich treibe Sport weil ich durch meine Leistung Aufsehen erregen will. | 1 | 2 | 3 | 4 |
| 70.Ich treibe Sport weil ich die Vertrauensbasis zu meinem/meinen Sportpartner(n) schätze. | 1 | 2 | 3 | 4 |

**Ganz herzlichen Dank für Ihre Mitarbeit!**

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## 8.4 Additional information on the application of the sport model

### 8.4.1 Instructions for the evaluation of feedback training

The following visual instructions were presented to the participants of the evaluation study. Both the experimental and the control groups received equal exercise instructions. The information regarding the audio feedback was excluded for the control group.

INSTRUKTION B

Step 1

**Hallo, wie heißt Du?**

Ich bin Dein digitaler Skilehrer. Hast Du Deine Ausrüstung schon bekommen? Perfekt! Dann hilf mir kurz, dass ich mich auf Dich einstellen kann.

Bitte stelle Dich mit hüftbreiter Skistellung so hin, wie es auf der mittleren Abbildung zu sehen ist. Beuge Dein Sprung-, Dein Knie und Dein Hüftgelenk leicht. Bleib‘ mindestens fünf Sekunden stehen!

**Ein kleiner Hinweis: Du musst so stehen, dass Deine Schienbeine vorne die Skischuhe berühren.**

Info: Standübung

INSTRUKTION B

Step 2

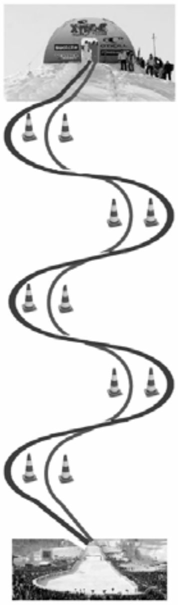
**Auf geht‘s!**

Machen wir unsere erste Abfahrt. Damit ich erkennen kann, wann es los geht, spring‘ bitte ein Mal mit beiden Beinen in die Luft.

Jetzt kannst Du starten. Fahre Kurven bis ans Ende der Piste und fahre mit dem Förderband wieder hinauf.

**Ein kleiner Hinweis: Du kannst die Geschwindigkeit und die Größe der Kurven frei wählen. Fahre so, dass Du Dich wohl fühlst.**

Info: 1 Freifahrt



Step 3

**Schau'n mer mal!**

Zeit für einen ersten Test. Wir wollen einmal sehen, wie gut Du schon Ski fährst. Dafür machen wir zwei Abfahrten durch den Slalom. Du hast verschiedene Fahrspuren zur Auswahl:

Blau: Mittlere Kurven, langsameres Tempo

Rot: Kleine Kurven, schnelleres Tempo

Bleibe in der von Dir gewählten Spur. Du musst Dich vor dem ersten Tor entscheiden.

**Ein kleiner Hinweis: In der zweiten Testfahrt muss die andere Spur gewählt werden.**

Info: 2 Fahrten

INSTRUKTION B

Step 4

**Gewusst wie!**

Innerhalb des vorgegebenen Korridors sollst Du Kurven fahren. Achte für die beiden nächsten Abfahrten besonders auf Deine Position über dem Ski: Stehst Du zu weit hinten, werde ich Dich über einen Piepton korrigieren.

NICHT ZU WEIT HINTEN:

NICHT ZU WEIT VORNE:

NICHT GEBEUGT:

SONDERN MIT AUFRECHTEM OBERKÖRPER IN MITTLERER POSITION:

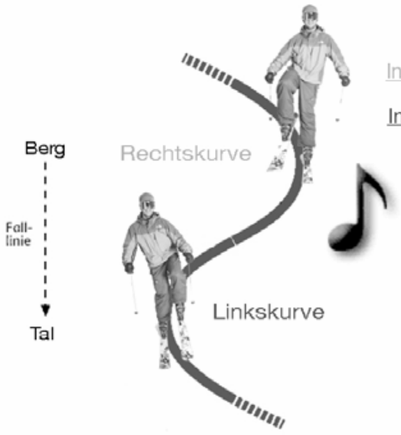
**Ein kleiner Hinweis: Erinnere Dich an die mittlere Position, die Du vor der 1. Abfahrt für 5 Sekunden eingenommen hast!**

Info: 2 Fahrten

**INSTRUKTION B** Step 5

**Ein Balance-Akt!**

Für die nächste Abfahrt ist Gleichgewicht gefragt. Wo Du im Korridor Schwünge fährst, bestimmst Du selbst. Deine Aufgabe: Versuche Kurven zu fahren und dabei jeweils ein Bein anzuheben. Ich zeige Dir, wie ich das meine:




In der Rechtskurve hebst Du das rechte Bein hoch!

In der Linkskurve hebst Du das linke Bein hoch!

Hast Du die Aufgabe erfüllt, dann ertönt in Deinem Kopfhörer die Aussage: „Super!“

War die Aufgabe nicht erfüllt, dann erinnere ich Dich und sage: „Innenski hoch.“

**Ein kleiner Hinweis: Versuche Dein Bein VOR der Kurve anzuheben. Damit fährst Du automatisch auf dem wichtigen Außenski!**

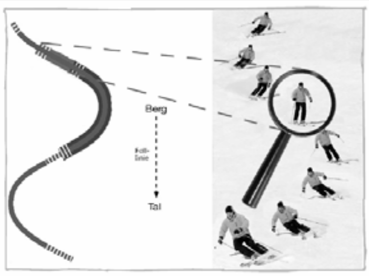
Info: 1 Fahrt

**INSTRUKTION B** Step 6

**Bewege Dich auf dem Ski!**

Skifahren ist Sport. Sport ist Bewegung. Fahre bei der nächsten Abfahrt Kurven innerhalb des Korridors. Versuche zwischen den Kurven immer wieder in die mittlere Position zu kommen. Dafür musst Du Dich bewegen. Ich zeige Dir die mittlere Position noch einmal. Und ich zeige Dir wann Du diese einnehmen solltest:

MITTLERE POSITION: UND HIER SIEHST DU WANN DU SIE EINNEHMEN SOLLST:




Wenn Du es in die mittlere Position geschafft hast, hörst Du im Kopfhörer: „Sauber!“
Hast Du die richtige Position nicht erreicht, sage ich zu Dir: „Weiter vor!“

Info: 5 Fahrten


### 8.4.2 Questionnaire for the evaluation of subjective impressions during feedback training

The following questionnaire was presented to the participants of the evaluation study. Both experimental and control group received the questionnaire. The specific questions concerning the experience with the training feedback system (questions 1 to 11) were excluded for the control group.

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**Fragebogen „Digitaler Skiunterricht“**

1. **Haben Sie den Digital Skiing Coach während der Abfahrt als störend empfunden?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

2. **Hatten Sie das Gefühl das Sie mit dem Digital Skiing Coach sicherer Skifahren?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

3. **Hat Sie der Digital Skiing Coach vom Skifahren abgelenkt?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

4. **Haben Sie persönlich auf das Feedback reagieren können?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

5. **Haben Sie den Eindruck, der Digital Skiing Coachk hilft bei der Vermittlung einer Bewegungsvorstellung?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

6. **Können Sie sich vorstellen auch privat mit einem solchen System Ski zu fahren?**

1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

7. **Wie häufig würden Sie persönlich den Digital Skiing Coach an Skitagen einsetzen?**

1 immer
2 ab und zu
3 eher selten
4 nie

8. **In welchen anderen Sportarten könnten Sie sich den Einsatz eines digitalen Trainers vorstellen?**

______________________________

______________________________

______________________________

9. Was würden Sie an diesem System verbessern?

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

10. **Treiben Sie Sport?** (ausser Skifahren)
O ja O nein

11. **Wenn ja, welche Sportarten?**

______________________________

______________________________

12. **Wie oft treiben Sie Sport?**
1 täglich
2 mehrmals pro Woche
3 einmal pro Woche
4 einmal im Monat

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**Fragebogen „Digitaler Skiunterricht“**

13. **Aus welchen Gründen treiben Sie Sport?** (Bewerten Sie die folgenden Aussagen je nach Grad der Zustimmung. Bitte ankreuzen.)

a) Ich treibe Sport weil ich Spaß an der Bewegung habe.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Ich treibe Sport weil es mir Freude macht mich im Freien zu bewegen.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

c) Ich treibe Sport weil ich mich dann besser entspannen kann.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

d) Ich treibe Sport als körperlicher Ausgleich zur Ausbildung / zur Arbeit.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

e) Ich treibe Sport weil ich dabei Alltags-stress abbauen kann.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

f) Ich treibe Sport um mich richtig auszutoben.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

g) Ich treibe Sport weil ich den Nervenkitzel dabei mag.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

h) Ich treibe Sport weil ich das Risiko dabei mag.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

i) Ich treibe Sport weil ich mich danach wohl fühle.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

j) Wenn ich Sport treibe werde ich nicht so leicht krank.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

k) Wenn ich Sport treibe schütze ich mich vor Verletzungen.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

l) Ich treibe Sport, um mich konditionell fit zu halten.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

m) Ich treibe Sport, um eine gute Figur zu haben.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

n) Ich treibe Sport, weil mich die Vielfalt unterschiedlicher Bewegungsabläufe reizt.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

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**Fragebogen „Digitaler Skiunterricht"**

o) Ich treibe Sport, weil mir die Möglichkeit der Bewegungsfreiheit beim Sport gefällt.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

p) Ich treibe Sport, um etwas mit anderen Leuten zusammen zu machen.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

q) Ich treibe Sport, um neue Leute kennen zu lernen.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

r) Ich treibe Sport, weil ich die Vertrauensbasis zu meinem/meinen Sportpartner(n) schätze.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

s) Ich treibe Sport, um meine eigene Leistungsfähigkeit zu verbessern.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

t) Ich treibe Sport, um mich mit Anderen zu messen.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

u) Ich treibe Sport, weil ich durch meine Leistung Aufsehen erregen will.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

14. **Was gefällt Ihnen am alpinen Skisport?** (Bitte treffen Sie Aussagen zu den nun folgenden Schlagworten!)

*Wahrnehmen der Geschwindigkeit*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Beschleunigung (z.B. bei Kurvenfahrten) spüren.*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Nervenkitzel selbst erzeugen*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Bewußtes Eingehen von Risiken*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Mit Anderen Sport treiben*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Anforderungen an meine Bewegungsfertigkeit meistern*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Bewegungsfreiheit (unterschiedliche Bewegungsabläufe) genießen*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

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**Fragebogen „Digitaler Skiunterricht"**

*Körperliche Leistungsfähigkeit verbessern*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

*Koordination verbessern*
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

15. **Bewerten Sie den heutigen Skitag.** (Bitte kreuzen Sie auf der vierstufigen Skala an.)

*a) Waren sie durch die Testsituation irritiert?*
überhaupt nicht — sehr stark
1 2 3 4

*b) Wie empfanden Sie persönlich die Anforderungen in den Abfahrten?*
sehr gering — sehr hoch
1 2 3 4

*c) Sind Sie zufrieden, mit Ihrer Leistung?*
überhaupt nicht — sehr stark
1 2 3 4

*d) Waren Sie während den Abfahrten bei der Sache?*
überhaupt nicht — sehr stark
1 2 3 4

*e) Fühlten Sie sich bei den Abfahrten sicher?*
überhaupt nicht — sehr stark
1 2 3 4

16. **Machten Ihnen die Abfahrten Spaß?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

17. **Machten die Abfahrten Spaß weil man sich selbst bewegen mußte?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

18. **Machte es Spaß weil Sie eine Bewegungsvorstellung/Hilfestellung hatten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

19. **Hat Ihnen die Beschleunigung in den Kurven Spaß gemacht?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

20. **Hatten Sie das Gefühl dass sich die Kurvenbeschleunigung während der Trainingsphase erhöhte?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

21. **Empfanden Sie das Gefühl als angenehm?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

22. **Hatten Sie das Gefühl dass sich die Kurvenbeschleunigung während den Abfahrten verminderte?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

23. **Empfanden Sie das Gefühl als angenehm?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

24. **Fühlten Sie während den Abfahrten ein Kribbeln im Bauch?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

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**Fragebogen „Digitaler Skiunterricht“**

25. **Verstärkte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

26. **Verminderte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

27. **Empfanden Sie das Gefühl als angenehm?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

28. **Hatten Sie während den Abfahrten das Gefühl dass Ihr Körper in die Kurve gedrückt wird?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

29. **Verstärkte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

30. **Verminderte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

31. **Empfanden Sie das Gefühl als angenehm?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

32. **Hatten Sie während den Abfahrten das Gefühl als würden Sie aus der Kurve gehoben?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

33. **Verstärkte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

34. **Verminderte sich das Gefühl während den Abfahrten?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

35. **Konnten Sie in die Beschleunigung eintauchen?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

36. **Empfanden Sie nach den Abfahrten ein beschwingtes Gefühl?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

37. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

38. **Fanden Sie die Abfahrten belebend?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

39. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

40. **Waren die Abfahrten für Sie berauschend?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

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**Fragebogen „Digitaler Skiunterricht“**

41. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

42. **Waren die Abfahrten erfrischend?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

43. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

44. **Waren sie nach den Abfahrten euphorisch?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

45. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

46. **Fühlten Sie sich nach den Abfahrten lebendig?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

47. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

48. **Fühlten Sie sich nach den Abfahrten stimuliert?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

49. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

50. **Fühlten Sie sich nach den Abfahrten voller Energie?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

51. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

52. **Fühlten Sie sich nach den Abfahrten positiv gestimmt?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

53. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

54. **Fühlten Sie sich nach den Abfahrten wie nach einer Adrenalinausschüttung?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

55. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

56. **Fühlten Sie sich nach den Abfahrten erholt?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

57. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

58. **Fühlten Sie sich nach den Abfahrten leicht?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

59. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

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**Fragebogen „Digitaler Skiunterricht“**

60. **Fühlten Sie sich nach den Abfahrten wie unter Strom?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

61. **Haben Sie dieses Gefühl immer beim Sporttreiben?**
O ja O nein

62. **Machten Ihnen die Abfahrten mit kleinen Kurven mehr Spaß als die mit großen Kurven?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

63. **Empfanden Sie Nervenkitzel?**
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

64. **Schätzen Sie Ihre Gefühlslage ein, die Sie während der Abfahrten hatten.** (Benutzen Sie nachfolgende Gegensätze. Markieren Sie eine Zahl ohne lange zu überlegen.)

| | | | | | |
|---|---|---|---|---|---|
| angeregt | 1 | 2 | 3 | 4 | gelangweilt |
| glücklich | 1 | 2 | 3 | 4 | traurig |
| mutig | 1 | 2 | 3 | 4 | ängstlich |
| zerfahren | 1 | 2 | 3 | 4 | konzentriert |
| sicher | 1 | 2 | 3 | 4 | unsicher |
| stark | 1 | 2 | 3 | 4 | schwach |
| wachsam | 1 | 2 | 3 | 4 | schläfrig |
| abgelenkt | 1 | 2 | 3 | 4 | bei der Sache |
| angespannt | 1 | 2 | 3 | 4 | entspannt |
| zufrieden | 1 | 2 | 3 | 4 | unzufrieden |
| engagiert | 1 | 2 | 3 | 4 | gleichgültig |
| frei | 1 | 2 | 3 | 4 | verkrampft |
| leichtfüßig | 1 | 2 | 3 | 4 | träge |
| selbstvertrauend | 1 | 2 | 3 | 4 | misstrauisch |
| verschlossen | 1 | 2 | 3 | 4 | offen |
| unbeschwert | 1 | 2 | 3 | 4 | belastet |
| wetteifernd | 1 | 2 | 3 | 4 | kooperativ |
| aktiv | 1 | 2 | 3 | 4 | passiv |

**Nachfolgend finden Sie Aussagepaare. Bewerten Sie jede Aussage.**

65.
a) Ich bin beim Skifahren zufrieden, wenn ich vom Gefühl her viele gute Schwünge gefahren bin.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Ich bin beim Skifahren zufrieden, wenn ich besonders schnell Kurven fahren kann.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

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**Fragebogen „Digitaler Skiunterricht“**

66.
a) Wenn ich zum Skifahren gehe, richte ich mich danach, ob mir die Piste gefällt oder nicht.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Skifahren macht mir Spaß, wenn ich Bewunderung erfahre.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

67.
a) Es ist wichtig, dass ich nach dem Skifahren über meine Erlebnisse berichten kann.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Es ist mir egal, wie ich auf andere wirke, Hauptsache ich fühle mich bei jedem Schwung gut.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

68.
a) Die Qualität einer Abfahrt ist mir egal, Hauptsache ich habe während der Abfahrt Spaß.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Wichtig ist, dass ich mit einer Abfahrt zufrieden bin.
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

69.
a) Beim Skifahren gilt das Motto: „Sicherheit geht vor Leistung“
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

b) Beim Skifahren gilt das Motto: „Leistung geht vor Soziales!“
1 trifft voll zu
2 trifft größtenteils zu
3 trifft teilweise zu
4 trifft nicht zu

70. Angaben zur Person:

Vorname:___________________________

Name:_____________________________

Selbstverständlich behandeln wir sämtliche Angaben streng vertraulich. Die Fragebögen werden nach der Auswertung vernichtet. Eine spätere Zuordnung der von Ihnen gegebenen Antworten zu Ihrer Person ist nicht möglich.

Vielen herzlichen Dank für Ihre Teilnahme!

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