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SPECIFIC CHARACTERISTICS OF SPORTS EQUIPMENT

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ABSTRACT
It is hypothesized that the quality of sport equipment regarding the three most important consumer (athlete) relevant aspects can be enhanced by taking into account and handle specific characteristics of sports equipment during the design process. The target of the present study is to first find measurable criteria (characteristics) that have an impact on the design process. This step does not include measurable criteria to assess the benefit of possible interventions during the design process. A Wideband Delphi Analysis was performed in order to approach consensus on the nature of specific characteristics of sports equipment.
First, a prepared list of statements about characteristics was merged to a questionnaire and eventually presented to eight experts from the fields sports science, engineering, human science, and industrial design. The results were discussed in a workshop, completing the list of statements and working out further differentiations for some of the statements. Two core issues for the design of sports equipment are the safety aspect and fun as a driving motive using sports equipment. Safety in relation to sports is ambivalent, because safety in terms of functionality and reliability is generally demanded for sports equipment but accidents and harm are taken into account in certain situations by the user. Also fun is a multidimensional aspect in relation to sports: equipment, environment, kind of motion, socializing effects etc. Fun was, however, regarded as a singular facet in this study so far. Further investigation has to be performed together with sports psychologists to work out the different levels and impacts of fun.
The experts agreed very well on some of the characteristics like the domination of the look, the general absence of legal restrictions for the design and the use of sports equipment in most sports or the statement that simple motion patterns are preferred for leisure sports. Other issues were discussed very controversial, like the influence of competitive sports on the consumer market, the equipment's dynamic response to the athlete or the enhancement of personal performance through special equipment.
These characteristics have to be differentiated and quantified, were possible, to make them directly applicable as a supportive information pool for design projects in the task clarification and the conceptual phases.

Keywords: Sports equipment, interdisciplinarity, design for X

1 INTRODUCTION

1.1 Background
Sport has the power to unite people in a way little else can (Nelson Mandela). The increasing importance of sports regarding health and general well-being is evident. Staying healthy, being fit and having fun practicing sports of any kind is a top of the bill issue and functional and high quality sports equipment is selling well. This is partly reflected by overall sales numbers and turnovers. The US sports industry (including events), for instance, is seven times bigger than Hollywood, growing 3 percent per annum [5]. Traditional sports and upcoming trend sports bear a vast potential of completely new designs and the optimization of sports equipment from simple parts to innovations through transfer of high technology.
Despite this fact the global sports industry is highly fragmented regarding their overall number and their size. In a survey among 887 European companies with known turnover, 270 (30.4%) earn a

turnover of less than 0.9 M EUR [5]. There is, however, an immense growth in technological needs such as the increasing application of mechatronics in sports equipment the smaller and medium-sized companies cannot cope with only from their own resources [7]. Also legal needs like liability issues are of increasing importance due to modified jurisprudence in some countries. On the other side a new trend is set by companies from other branches, mainly high technology industry, aiming to enter the sports market with innovative products.
The Department of Sports Equipment and Materials, Technische Universität München, for instance is concerned with fatigue strength of bicycle parts in a pool project together with five partners from the bicycle industry. Another project was initiated with a partner from the mobile radio business to investigate on and design direct feedback systems linked to mobile devices as a possibility to give training support and advice on technique. These two examples taken just from one department show the wide range of tasks and efforts in the field of sports engineering.

1.2 Sports Engineering – A Definition

What is it now that is being called sports engineering? Or more precise: what is it that makes the area of sports engineering interesting for design research?
An answer to these questions seems necessary since sports engineering is the field the present study is adressed to and it is likely that the term is not well known in the classical engineering design area yet. As for the first question, the definition of a strongly related term, sports technology, was made by Heinemann and should be used in this context for further explanations. Thereafter sports technology are artefacts with the purpose to practice sports (that is equipment, e.g. bicycles), artefacts with the purpose to build such equipment (that is raw material, e.g. new combinations of carbon fibre) and specific or modified technologies to produce sports equipment, e.g. new weaving technologies for sailcloth [6]. Thus, one could conclude that sports engineering generally is the area of research and design that ultimately generates knowledge to build and support sports technology. Here, focus is put on the design of artefacts with the purpose to support and practice leisure sports, namely sports equipment for leisure sports.

1.3 Characteristics of Sports Equipment

A characteristic is defined as a distinguishable feature of a person or thing, hence any measurable property of a device measured under closely specified conditions [14]. As for sports equipment, it is proposed that characteristics cover features regarding design (form, function, material) and context of use (social aspects, interfaces etc.), distinguishing sports equipment from other products and making them unique in terms of the design task.
Characteristics of sports equipment can be used as an information pool acting bidirectionally between the process steps *initialization of a new design* – either a new product idea or a specified task – and *the task clarification* and the *conceptual design*, respectively (figure 1). The idea is that insights into the nature of a certain piece of equipment leads to new or better products eventually or, vice versa (see list of benefits below). So, fun could be a driving motive for using a piece of sports equipment and knowing about special motion patterns to generate fun very likely leads to innovative product ideas. The actual design process on the other hand may be enhanced because specific characteristics relevant for the design process can be taken into account after an idea or a task has been settled.

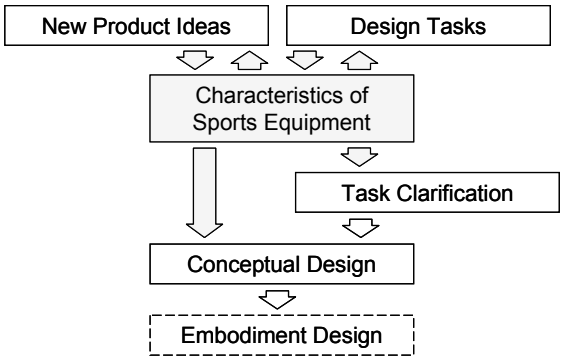

Figure 1. Impact of Characteristics of Sports Equipment on the Design Process after [13]

Regarding the design process, the concrete benefit of knowing such characteristics of sports equipment would be the following:

- Estimation of the necessity of pre-tests evaluating certain design parameters (e.g. biomechanical loads).
- Pre conceptual check of boundary conditions or limiting factors (e.g. legal restrictions).
- Support of the task clarification phase with specific facts (e.g. quantified kinematics, haptics).
- For the embodiment design, a structured overview of design relevant aspects (e.g. norms).

More benefits may evolve or one or another may be relativized within the study.

2 METHODS

2.1 Context and Research Questions

It is hypothesized that the quality of sport equipment regarding the three most important consumer (athlete) relevant aspects can be enhanced by taking into account and being able to handle specific characteristics of sports equipment during the design process. Now, the three main questions are:

- What are the three most important consumer relevant aspects and how can they be displayed?
- How can a supportive model for the design of sport equipment look like?
- What are specific characteristics of sports equipment?

The target of the present study is to first find measurable criteria (characteristics) that may have an impact on the design process. This step does not include measurable criteria to assess the benefit of possible interventions during the design process (see figure 2, 1 and 2).

2.2 Methodical Approach

Figure 2 shows an overview of the approach for the present study. In this paper the results of steps 1 to 4.2 are presented in full scope, steps 4.3 to 6 are only described methodically.

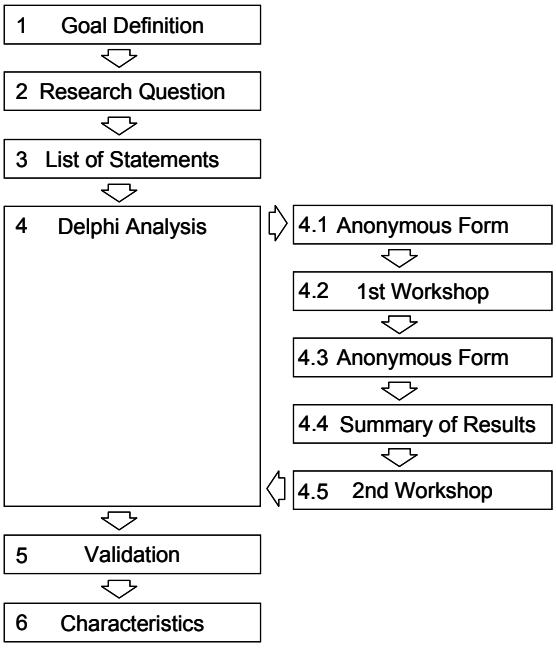

Figure 2. Methodical Approach

The Delphi Technique is an appropriate method for information procurement through a structured multi inquiry of experts [10]. Therefore it was chosen to facilitate the evaluation of a list of statements on the characteristics of sports equipment. The method was, notwithstanding its original design, also used to complete the list. This was done since there might have well been important statements that had not been considered before, but are, in any case, important for the focus of research. Therefore, a

variation of the basic method called Wideband Delphi [1] has been performed. Compared to the existing method, it involves a greater interaction and more communication between those participating [http://www.reference.com/browse/wiki/Wideband_delphi]. Although this was initially tried to evite because certain social interactive behavior as happens during a normal group discussion hampers opinion forming, it can be useful when experts can articulate their opinions in an anonymus questionnaire beforehand and then are only confronted with the outcomes for a further discussion.

Boehm's original steps to perform a Wideband Delphi analysis are the following:

1. Coordinator presents each expert with a specification and an estimation form.
2. Coordinator calls a group meeting in which the experts discuss estimation issues with the coordinator and each other.
3. Experts fill out forms anonymously.
4. Coordinator prepares and distributes a summary of the estimates.
5. Coordinator calls a group meeting, specifically focusing on having the experts discuss points where their estimates varies widely.
6. Experts fill out forms again, and steps 4 to 6 are iterated for as many rounds as appropriate.

The Delphi method has, however, suffered from several problems in the past, partially leading to poor results. The main reason herefore is that future developments can not always be predicted correctly due to a variety of unforeseeable effects. Also the initial Delphi method was not capable of making complex forecasts with interacting factors [15]. These external influences are difficult to measure but with respect to the presented aims (explorative approach) do not have that strong an effect on the outcomes. The internal consistency is quantified with the test-retest reliablity. Here, after a period of 3 weeks the experts are confronted with a form equal to the second anonymous form but before the final workshop (figure 2, 4.3).
As a first step towards a survey of characteristics of sports equipment it was tried to make a comprehensive list of statements preliminary to step 1 which methodically included literature research, analogy, comparison and brainstorming (figure 2, 3). The list served as a starting point for the specification in step 1. Step 6 is beeing omitted because, although possible future tendencies may influence the opinion building as well, the main focus of the study is to exhaustively find out the current traits of characteristics of sports equipment and to confirm them with an expert consensus on the statements. It was presumed that one loop comprising steps 1 to 5 is sufficient to get these results.
In fact focus is put to raise the outcomes' validity (figure 2, 5) since the circle of participants in the performed Delphi analysis does only represent a narrow sample of possible expert opinions. At first the end results of the Delphi analysis will be presented to at least one more accepted expert of the particular fields to check if estimations correlate [12]. These experts were taken from frequently cited literature references and the participants of the workshop themselves. Furthermore some of the characteristics summed in the list of statements and in the form are compared to other branches (e.g. automotive industry and consumer electronics industry) dealing with resembling core issues like intense man-machine interfaces, for instance. They are, for the very core issues, taken as a state-of-the-art reference leading to comparable results. Thus also an estimation from the reference's point of view is needed to see if it corresponds to the estimations made by the experts from fields related to sport equipment. The reference experts were taken from various university (Technische Universität München) department's industry contacts.

2.3 Study Design

The study is performed with a core team of eight experts from different fields of research related to sports. These fields comprehend sports science, engineering, human science, and industrial design. The following experts participated:

- Product development ---------- (Prof. Kristina Shea, TU Munich),
- Sports biomechanics ---------- (Prof. Senner, TU Munich),
- Sports psychology ---------- (Prof. Beckmann, TU Munich),
- Interaction design ---------- (Prof. Krohn, hgkz Zurich),
- Exercise diagnostics ---------- (Dr. Spitzenpfeil, TU Munich),

- Computer modelling ---------- (Dr. Böhm, TU Munich),
- Innovation in sports ---------- (Dr. Moritz, Sportkreativwerkstatt),
- Mechanical engineering ---------- (Matthias Blümel, TU Munich),
- Systematic training ---------- (Christoph Ebert, TU Munich).

The prepared list of statements was subdivided into 3 categories and put into a chance order for the questionnaire eventually:

- *Number of aspects:* sports equipment features a great variety of different characteristics regarding its design and use – this variety should be displayed entirely.
- *Complexity of focus:* many characteristics can take a wide range of possible values – this range should be determined for each of the characteristics.
- *Interaction of different aspects:* many characteristics interact strongly between each other – the nature of interaction should be described for each interaction.

For the the 1st anonymous form (figure 2, 4.1), more than 1 question per item and a total number of 51 questions were formulated to cover the statements. The first workshop was held on November the 13th 2006 and was conducted by the study's author.

3 RESULTS

3.1 List of Statements

The following table shows the list of statements that served as a basis for the first anonymous form as specified in chapter 2.2. The linked statements emphasize the analogy between the prepared items and the ones named by the experts in the open question prefacing the 1st anonymous form: "What do you think is special about sports equipment compared to other products?".The question aimed at a spontaneous response as a warm up for the following.

Table 1. List of statements and Correlation with Expert's Spontaneous Namings

category	topic	q-no.		spontaneous statements experts
number of aspects	fun is a driving motive	**3.2, 3.3, 3.5, 3.7**	↔	has to produce fun
	socialication effect of sport equipment through group specific design	**3.17, 3.18,. 3.21**		
	impact of trend sports on consumer behaviour	**3.9**		
	impact of sports trends on consumer behaviour	**3.19**		functionality is more important
	impact of design on trends	**3.15**		design follows function
	effect of safety equipment is taken into account/accidents are expected	**3.6, 3.11, 3.29**		common interest
	sports equipment as auxiliary of prevention against harm	**3.12**		fame
	sports equipment as means of rehabilitation after desease or surgery	**3.32**		very complex user-equipment interface
	sports equipment as means of compensation of office work	**3.4**		
	high number of individual inventiveness	**3.8, 3.10, 3.30**	↔	short innovation periods
	very short innovation/life cycles	**3.20**		
	approaches for leightweight structures	**3.1**	↔	fashion
	highly dynamic loading cases	**3.27**		
	extension of design into field of accessoires as a special attraction	**3.13, 3.28**	↔	hast to fit to many different target groups
	no primary legal restrictions for the design of sports equipment	**3.22, 3.25, 3.26**		functional
	mostly no obliging education for using a piece of sports equipment	**3.14, 3.16**	↔	specific
	individualization effect of sports equipment	**3.23, 3.24, 3.31**		
complexity of focus	relatively low expenditure for development of new equipment	**4.1**		
	high market impact of successful competition equipment	**4.2, 4.5**	↔	technology for high performance sports
	intensity of response from equipment	**4.3**		
	mass customization is a prior goal	**4.4**		
	tolerated fails of specifications by the user	**5.7, 5.10**	↔	strong emotional attachment
interaction of aspects	psychological addiction due to the generation of special thrills	**5.4, 5.5**	↔	emotional component
	importance of design besides functional requirements	**5.1, 5.8**	↔	stylish
	direct relation of performance display/physiological gross efficiency	**5.13, 5.14**	↔	marketing masks design
	adaptin to antropometry (kinematics-antropometry)	**5.2, 5.3**	↔	optimal interaction with human main target
	optimization of ergonomy (kinematics/ease of handling - ergonomy)	**5.6, 5.12**		
	motor activity as a challenge	**5.9, 5.11**		
	sports equipment to improve personal performance	**5.9**	↔	competition

The highlighted items on the right hand side ob table 1 were either new to the list or affect aspects not directly related to sports equipment but rather the athlete or the society in general.

3.2 Answer Patterns of 1st survey

The boxplot diagram was chosen to display the responses' variances (ordinate) on the ordinale rating-scale shown in figure 3. The outcomes are shown in order of the list of statements' topics and the assigned questions (abscissae), clustered and linked to the corresponding categories in figures 4 to 7.

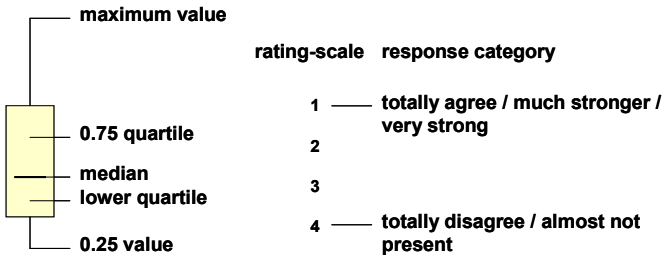

Figure 3. Boxplot Legend (left) and Rating Scale Legend (right)

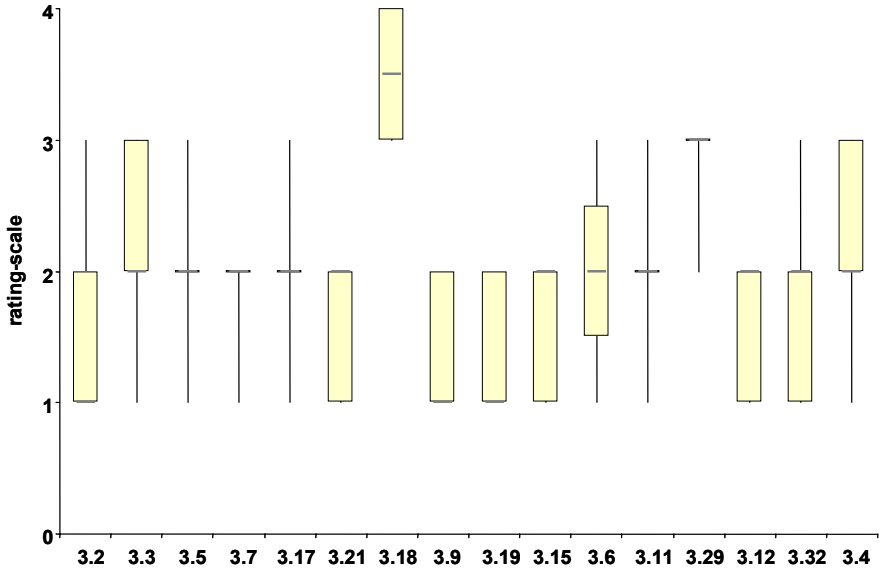

*Figure 4. Answer Pattern of Category **Number of Aspects***

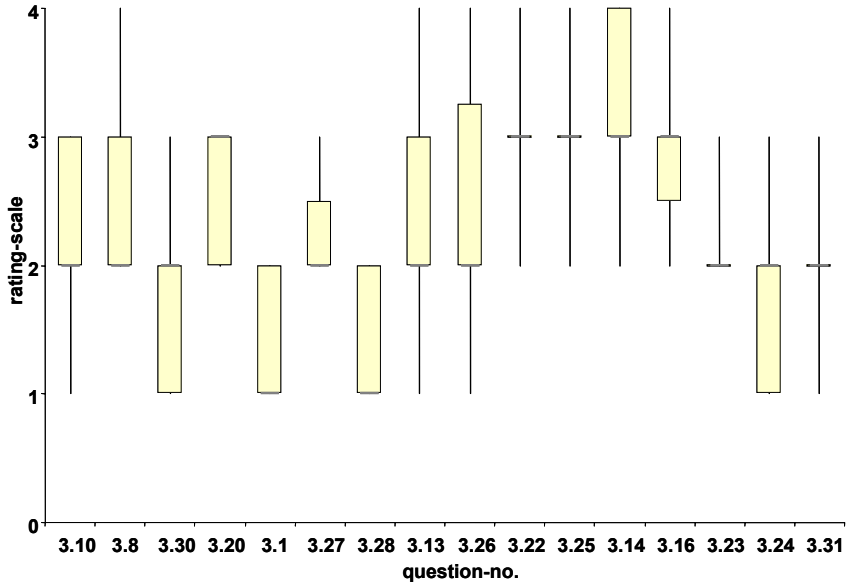

*Figure 5. Answer Pattern of Category **Number of Aspects***

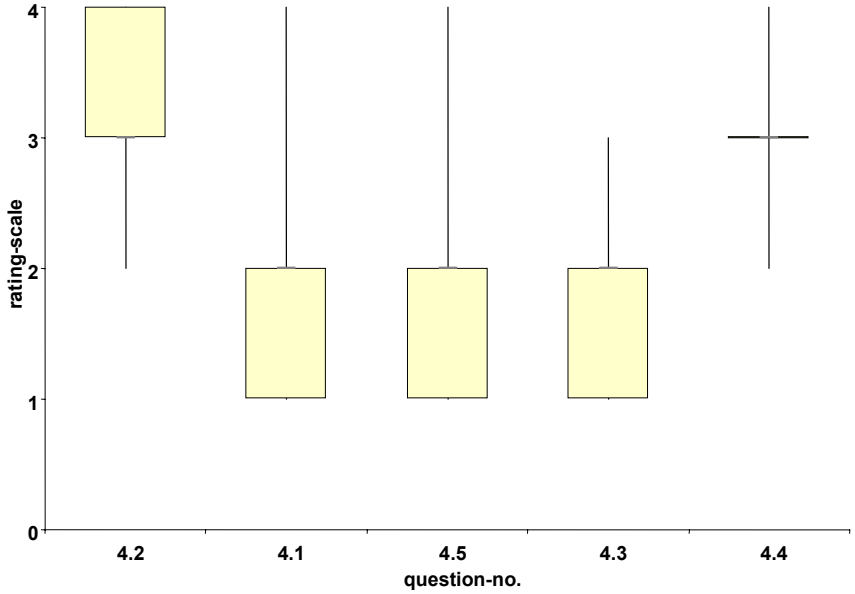

Figure 6. Response Distribution of Category ***Complexity of Focus***

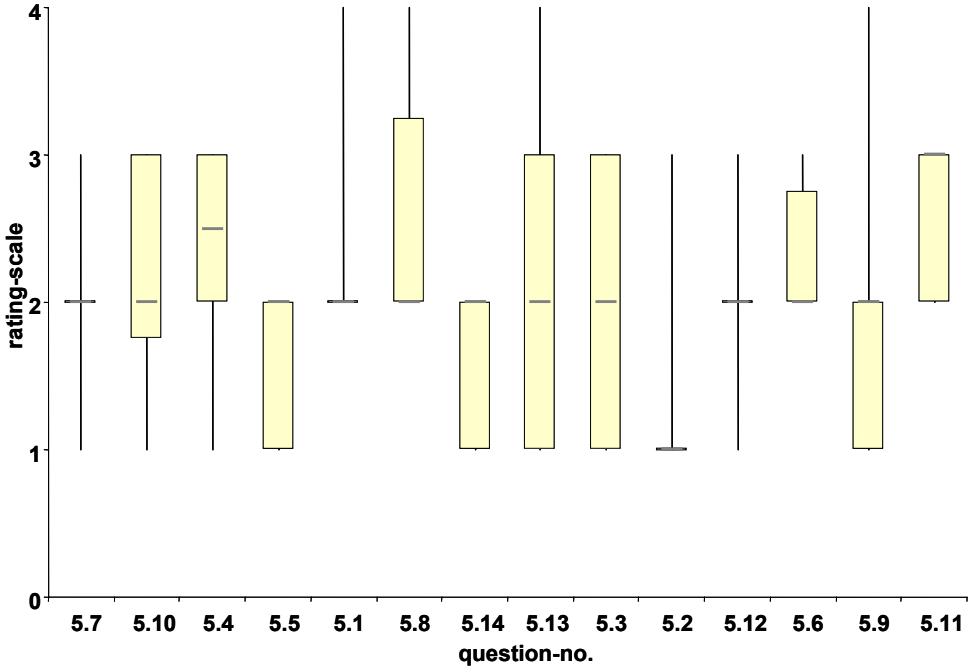

Figure 7. Response Distribution of Category ***Interaction of Different Aspects***

4 DISCUSSION

4.1 General Remarks

Some statements of the form's opening question (see 3.1) are not concerning sports equipment and therefore left out (e.g. fame). The rest of the new statements will be included for the 2nd anonymous survey.

The experts gave some remarks on the construction of the form as well. Some items, especially the ones on fun and safety, were not formulated specific enough. Hence, these items asked for more than one entitiy and therefore must be focused. These items nevertheless are very important items since they express attitudes of users (athletes, sportsmen) towards design relevant aspects directly related to market success (see 4.2).

Despite the even number of response categories and therefore the absence of a center category, a clear tendency of the answers towards the middle response categories, expressed through the medians in the boxplots, can be detected. Although categories 2 and 3 are not exactly neutral, this is a hint to formulate the questions even more provoking for the 2nd form to possibly get more polarizing results.

4.2 List of Statements

The original list of statements already covered most of the aspects named by the experts spontaneously in the opening question. This, of course, does not imply that the list is complete already, but shows that these aspects are considered as important characteristics of sports equipment by the experts as well. Also the list should not be regarded as a static document, some of the items may have to be updated or even new may be added from time to time. The challenge now is to enrich the list with statments from the free discussion of the 1st workshop and to drop or modify some of them.

4.3 Anonymous Form and Workshop

The graphs in the results chapter show clearly that the experts agree very well on some of the items. This is stated for results with a low deviation (+/-1) and a low 0.25 and 0.75 quartile. In detail these were the results of questions 3.5, 3.7, 3.11, 3.17, 3.22, 3.23, 3.25, 3.29, 3.31, 5.5, 5.6, 5.7, 5.11, 5.14, which are discussed in the following:

For category *number of aspects*

- fun is a driving force, but dependent on the equipment,
- the risk of injury is often supressed by users,
- sports equipment is socially more polarizing than other products,
- the design of sports equipment is mostly free from legal restrictions,
- safety aspects play a minor role for sports equipment compared to other products.

Although a consensus was reached regarding these items, some points were discussed intensely. The fun item still is not represented in a satisfying way. Prof. Beckmann remarket that the different aspects of fun and the relation to the human psyche has to be worked out more detailed. The safety issue was discussed in the context of bicycle sports: people would consider a crash going downhill with a mountain-bike consciously – but therefore rely on the capacity of their bicycle and the effect of protection equipment with radical consequences for the design of these pieces of equipment: a car is not build to be crashed, for instance. A suggestion was made to distinguish between the risk of acute accidents and menacing harm due to strain over a longer period of time. These example points out that the safety aspect has to be treated way more differenciated (response category *important/not important* is just not enough), enhanced with information about legal prescriptions, crash mechanisms etc.

For category *complexity of focus*

- users of sports equipment tolerate fails of product specifications.

This consensus is at least questionable. In no way it should encourage designers not to meet product specifications, of course. But it can imply that – different from the automotive industry – regarding some traits of sports equipment less perfectionism (or with other words: overengineering) is accepted. This is, however, speculation and would have to be proofed within a seperate survey.

For category *interaction of different aspects*

- adaptability to antropometry is essential,
- users consider new equipment to enhance their activity,
- optics dominate trends in sports equipment,
- simple motion patterns are preferred for leisure sports,
- stimulating thrills cause psychological addiction.

Generally speaking, these characteristics are first approaches. They now have to be concretized, described and quantified (when possible) within the further step of the study.
On the other hand there were a number of items that were rated slightly different or even contrary. A partly consensus was stated for a low deviation (+/-1) and/or quartiles that sum up to a maximum of 1, not exceeding an overall deviation of 2. This is indeed a overall deviation equal to the results stated as "consensus", but quartiles summing up to 1 or more implies that more than 1 expert had a different opinion than the others which cannot be regarded as consensus. In detail these were the results of questions 3.9, 3.12, 3.15, 3.18, 3.19, 3.20, 3.21, 3.27, 3.28, 4.2, 4.3, 5.1, 5.2, 5.4, 5.8, 5.10, which are listed in the following:

For category *number of aspects*

- trend sports and sports trends stimulate the consumer behaviour,
- short innovation cycles,
- sports equipment as prevention against harm,
- design sets trends,
- socializing effects of sports equipment through group specific design,
- dynamic loading cases more prominent than in other products
- sports accessoires increase attraction to practice a certain sport.

For category *complexity of focus*

- level of R&D efforts for new designs is higher compared to other products,
- mass customization as a prior goal.

For category *interaction of different aspects*

- performance display is related to gross efficiency,
- interface configuration user/equipment is important for market success,
- function follows form,
- individual performance more enhanced through muscle strengthening for leisure sports,
- fun sports are only practiced from time to time.

The items subsumed under "partly consensus" have to be presented to the experts again within the next anonymous form providing also the results of the 1st survey. Some statements, like *performance display...* , have to be relativized according to the expert's remarks or differenciated for the next survey, like *interface configuration...*

Finally experts totally disagreed about some items. This was stated when the overall deviation exceeds 2 and the quartiles sum up to 1 or more. In detail, these were the results of questions 3.2, 3.4, 3.6, 3.8, 3.10, 3.14, 3.16, 3.24, 3.30, 3.32, 4.1, 4.5, 5.1, 5.3, 5.9, 5.13, which are listed in the following:

For category *number of aspects*

- fun is dependent on the environment,
- sports equipment as means of compensation to office work and rehabilitation,
- accidents are taken into account due to personal safety equipment,
- design of sports equipment allows individual inventiveness apart from professional background,
- education is obliging for using sports equipment,
- sports equipment is used for individualization,

For category *complexity of focus*

- impact of equipment from competitive sports,
- equipment's response to the athlete.

For category *interaction of different aspects*

- ergonomic design is essential,
- personal performance is enhanced through latest equipment.

Although these items will be presented to the experts along with the results, again some items have to be revised and/or differentiated, *impact of equipment from competitive sports, fun is dependent on the environment, education is obliging for using sports equipment,* for instance.

5 OUTLOOK

In the following, the 2nd anonymous form and the 2nd workshop have to be prepared, conducted and analyzed. So far, the experts signalized their interest in a further participation. In order to achieve valid end results, the outcomes of the 2nd workshop have to be presented to experts from corresponding fields.

The quantification of characteristics, were possible, will imply some effort since literature research has to be performed for each of the topics.

Some of the outcomes were already applied to current design projects, especially topics related to safety (relevant standards etc.) and motion patterns (clustering of information for feedback to user), successfully and partly proved their benefit. For future projects, a compendium will be prepared, containing basic information and quantification about the different characteristics, related to the categories presented here.

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