CONCEPTS IN SKI JUMPING BIOMECHANICS AND POTENTIAL TRANSFER TO OTHER SPORTS

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The specificity of ski jumping requires particular considerations and methodologies regarding the biomechanical context. In this paper some of these issues are presented and discussed. Furthermore, potential transfer of these concepts and methodologies to other sports will be presented. The topics cover aspects of conceptual considerations regarding experimental research, lab and field measurements, ski jumping specific methodologies, imitation exercises and the relevance of biomechanics research within the complex research network. Starting from ski jumping the conceptual issues are discussed for demonstrating the potential transfer to other sports and optional applications in order to provide scientifically based enhancement of performance, effect of training concepts, comfort and injury prevention.

KEY WORDS: imitation exercises, research network, conceptual and methodological transfer

INTRODUCTION: Ski jumping is a very specific sport regarding different aspects. It is almost exclusively performed as a competitive sport, needs rather high and specific organizational demands and spacious and expensive facilities. A ski jumping competition consists of two runs only with a total performance time between 6 and 12 seconds, depending on the size of the hill. During a hill training session usually 6-8 jumps are performed. This leads to a ratio between 'performance time' and 'rest time' of about 1:120. These conditions require high quality training regimes, including dry-land and hill training in terms of conditioning and specific coordination training. Furthermore, research on motor control, training theory and biomechanics provide an essential support for improving the quality of training and performance enhancement in ski jumping.
From the biomechanical point of view ski jumping covers many different issues that have to be considered and balanced accordingly in order to guarantee the highest possible level of performance and safety. Among others the most important ones are friction, drag, lift, explosive leg extension, production of angular momentum, joint and tissue loading and biomechanical aspects of equipment. Furthermore, also other issues like health, safety and fairness have to be considered.
The specificity of ski jumping within the biomechanical context requires selected and specific methodologies and considerations. Some of them will be presented and discussed in this paper and a transfer to other sports will be presented.

BIOMECHANICAL METHODS AND EXPERIMENTAL RESEARCH: Experimental biomechanical research can be arranged on different research levels (Fig. 1, Schwameder, 2011, modified). The basis of this pyramidal structure (level 1) consists of the description, the detection and the analysis of singular physical components (for ski jumping: maximal force, maximal rate of force development of the knee extensors). The next level (2) is the analysis of singular coordinative components (counter-movement jumps, squat jumps, drop jumps are appropriate representatives for this category in ski jumping). This is followed (3) by very specific exercises mimicking the 'real' performance tasks (imitation exercises that are commonly used when the number of performing real competitive motor tasks is restricted; also widely used in coordination and conditioning training). The forth level (4) is the analysis of competitive motor tasks under training conditions (wearable measurement units). The top of this pyramid (5) is built by the research during competitions (video systems, force plates implemented into the take-off table).
The diverse levels of research categories presented in Fig. 1 typically show different quality of *validity* (is measured what is intended to be measured) and *reliability* (accuracy of the measurement). Typically these two items move in opposite directions from top to bottom and vice versa. The highest level of validity only can be achieved in measurements during

competitions. At any lower level the quality of validity is reduced as only parts of the competition exercises or only singular coordinative or physical components can be investigated. On the other hand, the latter can be much better controlled leading to a high level of reliability. As on higher levels of the 'research pyramid' the investigation conditions cannot be sufficiently controlled, the reliability might be substantially reduced.

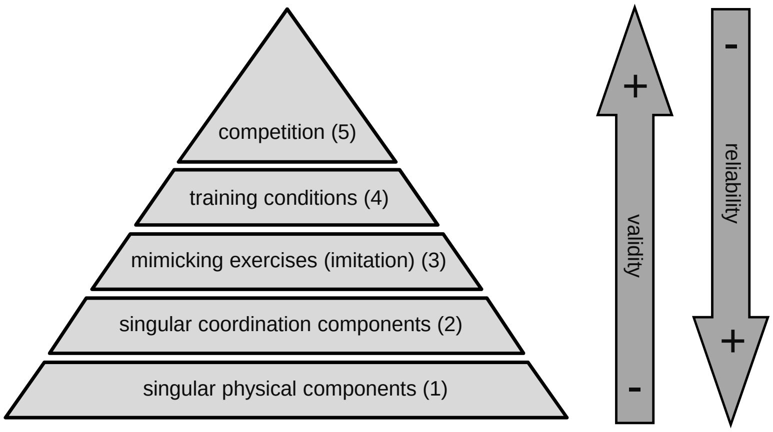

Fig. 1:
Levels (1-5) of experimental biomechanical research and classification regarding validity and reliability

The methodological range for data acquisition covers a wide field in ski jumping. The most important representative within the kinematic methodology in ski jumping is the video technique. In principle, video technique can be used in all levels of experimental research and can be applied in both ways, with fixed and with panned/tilted camera configurations (Virmavirta et al., 2005; Schwameder & Müller, 1995). A new approach of kinematic methodology is based on initial measurement units (IMUs) consisting of a combination of gyroscopes, magnetometers and accelerometers. These systems have already been successfully used for measuring the orientation of body segments over the entire hill jump (Chardonnens et al., 2010; 2011). Force plates measuring ground reactions forces in one, two or three dimensions are widely used for imitated take-offs and performance diagnostics. Pressure insoles are used for determining ground reaction forces in both hill jumps and imitated take-offs (Virmavirta & Komi, 2001; Virmavirta et al., 2001; Schwameder, 2007). Several take-off platforms of jumping hills are instrumented with force plate systems for measuring ground reaction forces perpendicular to the platform in hill jumps. Due to the high impact of aerodynamic forces in ski jumping on performance its determination in wind tunnel experiments has a very long tradition and is still widely used for improving the flight position. Another field of application of wind tunnel measurements are the determination of the effect of specific equipment (suits, helmets, skis, bindings) on aerodynamics in ski jumping. Muscle activation and muscle coordination patterns both in hill jumps and imitated take-offs are measured using surface EMG.

IMITATION EXERCISES: Imitated take-offs ('simulated take-offs') are important and widely used tools in ski jumping conditioning and coordination training as well as in performance diagnostics. Imitated take-offs are usually performed as dry-land exercises from static or quasi-static in-run positions with a subsequent take-off movement imitating the take-off in hill jumps (Fig. 2).

Elite ski jumpers present very high consistency in terms of reproducibility and variability in imitated take-offs. They are supposed to show very high coordinative affinity to hill jumps. This assumption has to be challenged, however, if the boundary conditions (aerodynamics, friction, duration) imitated take-offs and hill jumps are taken under consideration carefully. While the coefficient of friction between the skis and the ground (snow, ice, porcelain) is close to zero and the drag is high in hill-jumps, we find the opposite situation in imitated take-offs: high friction between the boots and the ground and no drag. The directions of the intended and the actual force application differ substantially in hill jumps due to drag. Hence, based on the low friction between the skis and the track the direction of the actual force application in hill jumps is fairly constant and is orientated more or less perpendicular to the track. In imitated take-offs, however, the intended direction of force application coincides with the actual jumping direction. This leads to considerable differences between hill jumps and imitated take-offs in terms of perceptive and biomechanical aspects. While the intended movements (perception of movement) with respect to force application are identical in hill jumps and imitated take-offs, the kinematics and kinetics of both jumps differ substantially.

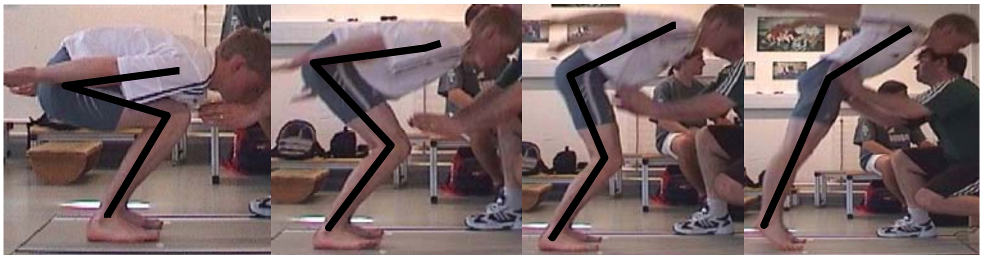

Fig. 2 : Kinematic sequence of an imitated take-off

It also has to be considered that the durations of the take-off in hill jumps (250–300 ms) and imitated take-offs (400–500 ms) differ remarkably (Schwameder, 2008; 2009).
Despite the discrepancies reported, imitated take-offs can be used reasonably in ski jumping specific technique and coordination training. The relevance of the imitated take-offs can be enhanced in case of combining it with performance diagnostics measurements (Schwameder, 2007). Coaches, athletes and supporting researchers, however, have to consider the presented and discussed aspects regarding the biomechanical and motor control differences between hill jumps and imitated take-offs in order to optimize the quality of training and to maximize ski jumping performance. Similar considerations have to be made accordingly when imitation exercises are performed in other sports.

RELEVANCE OF BIOMECHANICS WITHIN THE COMPLEX RESEARCH NETWORK: Ski jumping is a very complex sport and covers different interacting aspects. As discussed previously (Schwameder, 2011), the most important of these items are: performance, safety, health, fairness, social aspects, ethics and economy (Fig. 3). Biomechanics is unique in this context as it covers all of the named items and is able to provide answers to both basic and applied research questions. Currently the following topics are widely discussed among athletes, coaches and researchers: material and equipment, BMI regulation, wind and gate factor. Biomechanics can help to support this discussion on these topics on a scientific level.

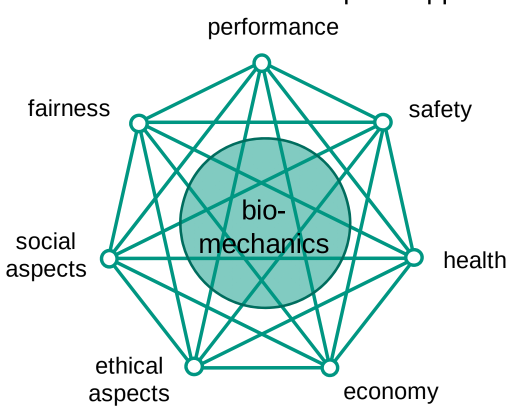

Fig. 3: Complex network of items in ski jumping. Biomechanics can be seen as the centre in this network

Material and equipment (including skis, bindings, suits, gloves and helmet) obviously determine ski jumping performance substantially. Consequently, a vast compendium of regulation exists in order to provide similar conditions for each individual jumper as good as possible. This question is directly connected with fairness, safety and health and also covers ethical aspects. But material and equipment also have social components, specifically within a national team and also between teams. Finally, regulations on material and equipment influence the production process of diverse items and cover also economic aspects.

The *BMI regulation* has been established several years ago for protecting ski jumpers from extreme weight loss and is based on biomechanical research including anthropometric and kinematic investigations. It has severe impact on health, performance, fairness and ethical questions. The social aspect of the BMI regulation covers both the weight issue within a team and the responsibility of the society with respect to the health of the athletes. Safety and economic aspects only play a minor role with this regard.

Wind and gate factor are also based on biomechanical research including complex mathematical models. These regulations have been established in order to compensate for changing wind conditions. Consequently, these issues are directly linked to performance, fairness and ethics. Wind and gate factor also have impacts on safety and health aspects. The social aspect must not be neglected as the regulations might cover tactical issues and has substantial impact on the attractiveness of ski jumping for spectators. Finally, the wind and gate factor regulations allow continuing competitions even in case of changing wind conditions within a run. This has important economic effects on handling competitions in general, but also for TV broadcasting with the consequence of making ski jumping even more attractive for on-site and TV spectators.

It is very important to discuss the questions and problems of the presented issues and topics on an evidenced based level. Biomechanical research is one of the key areas to provide the required information both for the singular items and within the complex network presented previously. This concept has the potential to be transferred to other sports, however, it has to be adjusted and applied accordingly.

REFERENCES:

Chardonnens, J., Favre, J., Cuendet, F., Gremion, G., and Aminian, K. (2010). Analysis of stable flight in ski jumping based on parameters measured with a wearable system. In R. Jensen, W. Ebben, E. Petushek, C. Richter & K. Roemer (eds). *Proceedings of the 28. International Symposium on Biomechanics in Sports,* (pp. 273-276). Marquette: Northern Michigan University.

Chardonnens, J., Favre, J., Cuendet, F., Gremion, G., and Aminian, K. (2011). A wearable system assessing relevant characteristics of the take-off in ski jumping. In E. Müller, S. Lindinger and T. Stöggl (eds.), *Science and Skiing V*, (pp. 599-607). Oxford: Meyer & Meyer Sport.

Schwameder, H., and Müller, E. (1995). Biomechanische Beschreibung und Analyse der V-Technik im Skispringen. *Spectrum der Sportwissenschaften 7*, *1*, 5-36.

Schwameder, H. (2007). Current and future aspects of ski-jumping biomechanics. In V. Linnamo, P. Komi and E. Müller (eds.), *Science and Nordic Skiing*, (pp. 225-236). Oxford: Meyer & Meyer Sport.

Schwameder, H. (2008). Biomechanics research in ski jumping – 1991-2006. *Sports Biomechanics,* 7, 1, 114-136.

Schwameder, H. (2009). Biomechanische Forschung im Skisprung – ein Überblick. *Spectrum der Sportwissenschaften,* 21,1, 68-95.

Schwameder, H. (2011). Challenges and issues in ski jumping biomechanics. In E. Müller, S. Lindinger and T. Stöggl (eds.), *Science and Skiing V*, (pp. 28-37). Oxford: Meyer & Meyer Sport.

Virmavirta, M., and Komi, P. V. (2001). Plantar pressure and EMG activity of simulated and actual ski jumping take-off. *Scandinavian Journal of Medicine and Science in Sport*, 11, 310-314.

Virmavirta, M., Perttunen, J., and Komi. P. V. (2001). EMG activities and plantar pressures during ski jumping take-off on three different sized hills. *Journal of Electromyography and Kinesiology*, 11, 141-147.

Virmavirta, M., Isolehto, J., Komi, P. V., Brüggemann, G. P., Müller, E., and Schwameder, H. (2005). Characteristics of the early flight phase in the Olympic ski jumping competition. *Journal of Biomechanics*, 38, 2157-2163.