APPLIED BIOMECHANICS IN ALPINE SKIING - PAST, PRESENT AND FUTURE ISSUES

Hermann Schwameder, Erich Müller, Christian Schiefermüller, and Josef Kröll
Department of Sport Science and Kinesiology, University of Salzburg, Austria
Christian Doppler Laboratory, "Biomechanics in Skiing", Salzburg, Austria

Biomechanics in alpine skiing has always been studied from an applied point of view. Among others biomechanical studies in alpine skiing can be categorised into the groups (1) biomechanical description and functional aspects of alpine skiing, (2) biomechanical analysis and determination of parameters related to performance in alpine skiing, (3) biomechanical testing, training and imitation exercises, (4) development, optimisation and tuning of the equipment, (5) modelling and simulation and (6) loading on the musculo-skeletal system and injuries in alpine skiing. This paper provides a literature review on biomechanics in alpine skiing with respect to these categories.

KEY WORDS: alpine skiing, ski equipment, modelling, loading.

INTRODUCTION AND OVERVIEW: Traditionally, biomechanics in alpine skiing has been studied from an applied point of view. Considerations and investigations regarding biomechanical aspects in alpine skiing actually have a rather long tradition (Müller & Schwameder 2003). The first published papers date back to the 1930s. In the 1960s alpine skiing was studied from a more theoretical point of view. Since the 1970s a large number of papers were published dealing with broadly oriented skiing techniques in ski instruction using various descriptive and analytic methods. Worth mentioning are the publications by Howe (1983) and Lind & Sanders (1997). The foundation of the international association 'Science and Skiing' in 1996 has proved to be of particular significance for the development of biomechanics in alpine skiing. At the congresses of this association in the years 1996, 2000 and 2004 numerous projects in biomechanics of alpine skiing have been introduced and published (Müller et al. 1997, Müller et al. 2001, Bacharach & Seifert 2004).
The literature review regarding biomechanics in alpine skiing provides a large number of papers that can be categorised into the following main groups:

- Biomechanical description and functional aspects of alpine skiing
- Biomechanical analysis and determination of parameters related to performance in alpine skiing
- Biomechanical testing, training and imitation exercises
- Development, optimisation and tuning of the equipment
- Modelling and simulation
- Loading on the musculo-skeletal system and injuries in alpine skiing.

All these aspects have always been investigated regarding the level of skiers one is interested in: beginners, recreational and competitive skiers.

Biomechanical description and functional aspects of alpine skiing: The description of movements and locomotion regarding biomechanical variables (kinematics, dynamics, muscle activity etc.) are the basics to study and to understand the skier's movements, the interaction with the equipment (boots and skis) and the interaction with the snow. Additionally, the fundamental description yields the basic information and the explanation how alpine skiing works in general. A detailed description is necessary to proceed with the analysis and the determination of variables related to performance in alpine skiing. One of the most important biomechanical descriptions (dynamics and muscle activity) was provided by Müller (1994) for the basic skiing techniques currently used at that time. A detailed description (3D kinematics and dynamics using Pedar insoles) of the techniques in elite slalom and giant slalom skiers during training runs were presented by Raschner et al. (1999). Description of muscle activity during alpine skiing was studied by Clarys et al. (1994), Hintermeister et al. (1995) and Nemeth et al. (1997). In the second half of the 1990s the so-called 'carving-skies' were established. The new material resulted in the development of new techniques. The first comparative description of the traditional technique and the carving-technique was presented by Raschner et al. (2001).

Biomechanical analysis and determination of parameters related to performance in alpine skiing: Since the 1980s biomechanical studies increasingly focus on the analysis and the determination of biomechanical variables related to performance in alpine skiing. Fetz (1991) considered the variables for finishing techniques and developed the "forward leaning technique" which is still used in slalom and giant slalom. Several papers deal with the optimisation of the trajectories of the CG and/or of the skis (Nachbauer & Rauch 1991, Reinisch et al. 1994). Recently Schiefermüller et al. (2004) presented a detailed analysis of the path of the CG in carving and provided a method to assess the quality of turning.

Biomechanical testing, training and imitation exercises: The quantity of training in high level competitive skiers can hardly be expanded. The consequence is the enhancement of the quality of training. This is directly connected with training evaluation using valid performance tests. Appropriate methods for both, juvenile and elite skiers, were presented by Aune et al. (1995), Reid et al. (1997) and Patterson et al. (2004). Another option to enhance the quality of training is the development of appropriate imitation exercises used in dry-land conditioning and technique training. Raschner et al. (1997) presented an electronically controlled training device to imitate slalom and giant slalom turns. Kröll et al. (2004) and Harb & Rogers (2004) developed specific inline skate and carving skate devices for ski-specific technique training on dry-land. Additionally, innovative training methods have been established to guarantee high quality conditioning training. Worth mentioning in this context are the methods of proprioceptive training (Gollhofer et al. 2001) and vibration training (Mester et al. 2001) in alpine skiing.

Development, optimisation and tuning of the equipment: The ongoing development of the geometry, construction and design of alpine skis requires fundamental basics regarding the effect of material and geometry changes on comfort and performance in alpine skiing. Several papers demonstrate significant relationships between the geometry of the skis and the trajectories (Casolo et al. 1997, Niessen & Müller 1999). Together with the increase of the side cut of the skis risers have been introduced to avoid the contact between the boots and the snow at high edging angles of the skis. It has been shown, however, that the risers also affect the vibration of the skis (Niessen et al. 1997) and serve for shorter running times (Niessen et al. 1998). The running surface of the skis obviously has important effects on the character of the skis in turning. Recently computer models were developed to study the effects of diverse preparation modes, waxes and snow conditions on the surface-snow interaction during skiing (Fauve et al. 2004). Beside the preparation of the skis with significant effects on metabolic variables and, consequently, on comfort and performance, the skis also can be tuned by risers of different height or stiffness and by optimising the position of the binding on the skis. Nigg et al. (2001) observed significant subject and leg specific effects of the binding position on comfort in recreational skiers and on performance in junior competitive skiers.

Modelling and simulation: The very complex situation with different interactions between snow, skis, boots and skier makes it difficult to measure biomechanical variables accurately enough. Therefore, the methods of modelling and simulation are increasingly used to receiving answers to specific questions. Models of the ski-skier-system were presented by Casolo et al. (1997). Federolf et al. (2004) developed a finite element model of the ski to investigate the interaction with the snow.

Loading on the musculo-skeletal system and injuries in alpine skiing: Loading on the musculo-skeletal system during alpine skiing and possible associations with injuries are very important issues, both for recreational and competitive skiers. Methodologically these issues are one of the most challenging ones as 3D kinematic together with 3D kinetic data have to be collected very accurately in the field to calculate joint loading in general and/or structure forces in particular. Among the most important papers presented so far are those by Quinn & Mote (1992), Herzog & Read (1993), Gerritsen et al. (1996) and Nigg (1997).

FUTURE ASPECTS: The purposes for the next steps in biomechanical research in alpine skiing highly depend on the target group one is focusing on. In this context a distinction should be made between beginners, recreational skiers and competitive skiers due to the different goals these groups are aiming at. The most important purposes can be described for the three groups as follows:

Beginners: (1) development of appropriate equipment to reduce learning time and increase safety aspects on the basis of biomechanical data and motor learning theories, (2) development of advanced learning strategies in alpine skiing based on biomechanical and motor learning fundamentals.

Recreational skiers: (1) effect of ski geometry, bending stiffness and torsional stiffness on comfort in skiing, (2) effect of ski equipment on fatigue, (3) analysis of ski equipment with respect to safety aspects (vibration, chattering, edging over etc.), (4) further development of ski boots with respect to optimising the combination of comfort on the one hand and force transfer to the skis on the other, (5) optimisation of the binding position on the skis, (6) improvement of ski binding release systems (eg. electronic bindings).

Competitive skiers: (1) effect of ski geometry, bending stiffness and torsional stiffness on performance in skiing, (2) analysis of trajectories in competitions with respect to ski geometry (specifically side cut), snow condition and running time, (3) tuning of the skis (preparation, height and stiffness of risers, binding position), (4) tuning of the boots regarding stiffness and optimal transfer of forces to the skis, (5) analysis of the ski-snow interaction, (6) development of exercises in conditioning (especially strength and strength endurance) and technique training with high coordinative affinity to snow skiing, (7) biomechanical testing routines to detect individual deficits regarding conditioning and coordinative aspects.

All theses purposes are closely connected with innovations and developments of biomechanical methods usable in alpine skiing field studies as: 3D kinematics (automatic tracking in field measurements), low weight 3D force and 3D moment measuring devices, appropriate models for simulations and valid models for loading calculations.

REFERENCES:

Aune, A., Schaff, P., Nordsletten, L. (1995). Contraction of knee flexors and extensors in skiing related to the backward fall mechanism of injury to the anterior cruciate ligament. Scandinavian Journal in Medicine, Science and Sports, 5, 3, 165-169.

Bacharach, D., Seifert J. (2004). Abstract bood of the 3rd International Congress on Skiing and Science (ICSS), Aspen, USA.

Casolo, V., Lorenzi, V., Vallatta, A. and Zappa, B. (1997). Simulation techniques applied to skiing mechanics. In Müller, E. et al. (eds), Science and Skiing. London: F&N Spon, 116-130.

Clarys, J.P., Publie, J., Zinzen, E. (1994). Ergonomic analyses of downhill skiing. J.Sports Sciences, 12, 243-250.

Fauve, M., Rhyner, H., Schneebeli, M. (2004). Influence of snow and weather characteristics on the gliding properties of skis. In Bacharach, D., Seifert, J. (eds). Abstract book of the 3rd ICSS, Aspen, USA, 88-89.

Federolf, P., Fauve, M., Lüthi, A., Rhyner, H., Ammann, W., Dual, J. (2004). Finite element simulation of a carving alpine ski. In Bacharach, D.,Seifert, J. (eds). Abstract book of the 3rd ICSS, Aspen, USA, 11-12.

Fetz, F. (1991). Biomechanik alpiner Zieleinlauftechniken. In: Biomechanik des alpinen Skilaufs (ed F. Fetz and E. Müller), Stuttgart: Enke, 124-130.

Gerritsen KG, Nachbauer W, van den Bogert AJ (1996). Computer simulation of landing movement in downhill skiing: anterior cruciate ligament injuries, Journal of Biomechanics, 29, 7, 845-854.

Gollhofer, A., Alt, W., Lohrer, H., Gruber, M. (2001). Functional adaptation following proprioceptive training for ankle and knee joint stabilization. In Müller, E. et al. (eds), Science and Skiing II. Hamburg: Kovac, 443-457.

Harb, H., Rodgers, D. (2004). Harb carvers: skiing substitute. In Bacharach, D., Seifert, J. (eds). Abstract book of the 3rd ICSS, Aspen, USA, 57-58.

Herzog W, Read L (1993). Anterior cruciate ligament forces in alpine skiing. Journal of Applied Biomechanics, 9, 260-278.

Hintermeister, R., O'Connor, D., Dillman, C., Suplizio, C., Lange, G., Steadman, J. (1995). Muscle activity in slalom and giant slalom skiing. Medicine and Science in Sports and Exercise, 27, 3, 315-322.