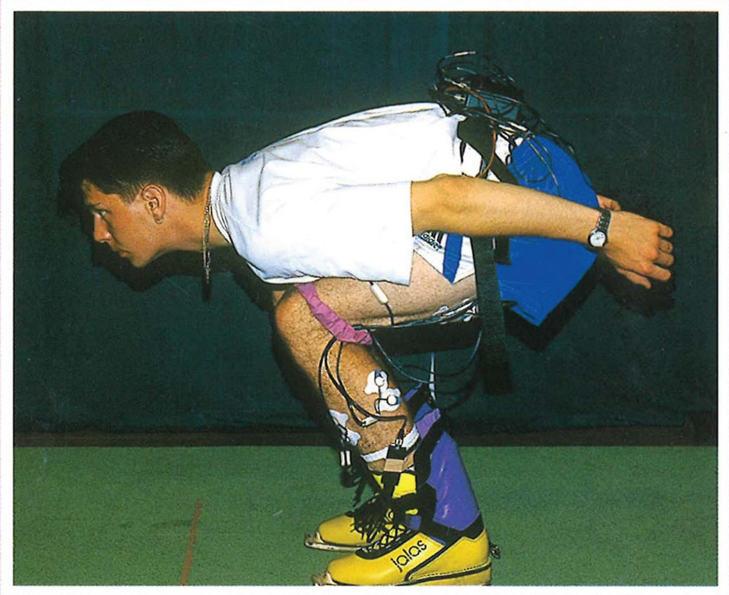
STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH

73

Mikko Virmavirta



Limiting Factors in Ski Jumping Take-off

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JYVÄSKYLÄ 2000

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Academic Dissertation

Neuromuscular Research Center,
Department of Biology of Physical Activity,
University of Jyväskylä

JYVÄSKYLÄN YLIOPISTO

JYVÄSKYLÄ 2000

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ABSTRACT

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The present study was designed to examine the factors which may hinder the execution of an effective take-off in ski jumping. Emphasis was placed on neuromuscular system of jumpers with special interest on balance of take-off under simulated laboratory and wind tunnel conditions. The test procedure for the Paromed Datalogger® used in the present study showed that this system could be used to measure pressure distribution under feet in ski jumping with only minor disturbance to jumper. The good fit between the measured relative pressure increase and the relative calculated centrifugal force during the inrun curve served as a rough indication of the validity of the system. Especially anteroposterior balance of jumper could be examined with the datalogger system. The results of this study showed that differences in plantar pressure and EMGs between the differently-sized jumping hills were smaller than expected. It seems that ski jumping training on small hills does not disturb the movement patterns for bigger hills and that it could also be helpful for special take-off training at low speed. The simulated and real ski jumping take-offs differed significantly in plantar pressure and muscle activation patterns. The centrifugal force due to the curvature of the inrun in real jumping hill conditions caused extra pressure under the fore and rear parts of the feet and therefore higher activation in all muscles. For the jumper, adequate sensory perception of this extra pressure and its release while entering the take-off table is obviously very important. The aerodynamic lift generated by the wind tunnel conditions brings simulated ski jumping take-off closer to field jumping conditions and helps the jumpers to perform take-off in the split second on the take-off table more effectively than has hitherto been believed possible. The reduced take-off time with higher rate of force production and minor changes in EMG emphasises the explosiveness of the ski jumping take-off.

Key words: Ski jumping, take-off, plantar pressure, electromyography, wind tunnel.

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ORIGINAL PAPERS

The present thesis is mainly based upon the following papers: In addition some data not presented in the papers are also included.

I Virmavirta M and Komi PV 2000. Plantar pressures during ski jumping take-off. J Appl Biomech 16: 312 – 318.
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II Virmavirta M, Perttunen J and Komi PV 2000. EMG activities and plantar pressures during ski jumping take-off in three different sized hills. J Electromyogr and Kinesiol, accepted.
https://doi.org/10.1016/S1050-6411(00)00047-X

III Virmavirta M, Kivekäs J and Komi PV. Take-off aerodynamics in ski jumping, submitted 1999. J Biomech, accepted.
https://doi.org/10.1016/S0021-9290(00)00218-9

IV Virmavirta M and Komi PV 2000. Plantar pressure and EMG activity of simulated and actual ski jumping take-off, submitted.
https://doi.org/10.1034/j.1600-0838.2001.110510.x

V Virmavirta M and Komi PV 2000. Ski jumping boots limit effective take-off in ski jumping, submitted.
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CONTENTS

1 INTRODUCTION

In ski jumping the final result is mainly determined by the length of the jump. The different phases of the jump - inrun, take-off, flight, and landing together with its preparation – all contribute to its length. Skill in ski jumping involves both ballistic and aerodynamic factors. The release velocity and the release position from the take-off table are ballistic factors; whereas the aerodynamic factors on the other hand include the gliding properties of the jumper/ski system (velocity, suit design, surface area, posture of the jumper/skis system, turbulence, resisting and lifting forces) during take-off and flight. The take-off is considered to be the most important phase for the entire ski jumping performance since it determines the initial conditions (velocity, angle of take-off, angular momentum and position of the jumper/ski system) for the subsequent flight. A successful take-off aims at maximal gain in vertical lift along with maintenance of the release velocity. Thus it is important to emphasise that it is the jumper and his ability to perform a skilful take-off and subsequent flight phase which finally determine the length of the jump. Mistakes during take-off cannot be corrected during the flight phase, but the benefits of a successful take-off action can be destroyed by mistakes during the flight.

Debates on the importance of the take-off in ski jumping performance have tended to follow developments in flight phase aerodynamics (jumping suits, flight style, etc.). In fact, the improvements in ski jumping aerodynamics (e.g. V-style, Mahnke and Hochmuth 1990) have increased the jumping distance so much that the precise effect of various take-off parameters on jumping distance may have been masked by other interacting factors, including the changing contribution of lift and drag forces. For this reason, aerodynamic aspects should also be added to any thorough analysis of take-off.

In ski jumping the take-off is performed under fairly extreme and changing conditions. High speeds, which result in an extremely short time available for execution of the take-off, and the pressures experienced during the inrun curve place special demands on the neuromuscular system of ski jumpers. Moreover, the different profiles of the ski jumping hills, with different radii of the inrun curve, have been assumed to make the initiation of take-off difficult especially when the jumper has to move from one jumping hill to another. The transition from the inrun curve to the flat take-off table is a crucial phase for the timing and co-ordination of movements, because of the sudden disappearance of the centrifugal force. Indeed, a good take-off already starts at the end of the inrun curve under the effect of centrifugal force (Schwameder 1993, Virmavirta & Komi 1993a). This probably guarantees a favourable muscle activation pattern for force production.

The present study attempts to examine the factors which may hinder the execution of an effective take-off in ski jumping. Special emphasis is placed on characterising the relevant neuromuscular functions of the ski jumper, as determined by simulated laboratory and wind tunnel conditions.

2 REVIEW OF THE LITERATURE

2.1 The characteristics of take-off performance

Kinematically, a rapid take-off movement can be characterised by changes in two major angles, i.e. the angle of the knee and the angle of the hip. The hip angle displacement is, on average, from 40° to 140° (Arndt et al. 1995, Schwameder and Müller 1995,) indicating that the hip extension continues in the air after the take-off edge has been passed. Similarly, the knee joint extension (from 70°to 140°) is not complete during the take-off table (Watanabe 1989). The "explosiveness" of the ski jumping take-off is characterised by a short take-off time (~ 0.25 – 0.30 s; Komi et al. 1974, Schwameder 1993) and also by the high angular velocity of the knee (over 12 rad$*s^{-1}$) reached just a few milliseconds prior to passing the take-off edge (Campbell 1980, Virmavirta and Komi 1994). In an optimal take-off the hip extension velocity is also relatively high (≈ 10 rad$*s^{-1}$) (Campbell 1980, Virmavirta and Komi 1994); this is caused mainly by thigh movement but with a smaller upper body extension (Arndt et al. 1995). The powerful knee extension movement results in a surprisingly high vertical velocity (normal to the take-off table) of the centre of mass of the jumper/ski system. Velocities as high as 2.3 to 3.2 m$*s^{-1}$ are not unusual (Komi et al. 1974, Virmavirta and Komi 1993a, Schwameder and Müller 1995). These high extension velocities demand effective utilisation of contractile characteristics of the fast twitch type skeletal muscle fibres (Tihanyi et al. 1982). Ski jumpers are reportedly of the fast muscle type as judged by their muscle fibre composition (Komi and Bosco 1978, Bosco and Komi 1979).

Even though the ballistic and aerodynamic factors during ski jumping take-off at least partly counteract each other and the control of these factors requires certain compromises, a good jumper performs this task much better than an average one. This has been demonstrated by the studies of Virmavirta and Komi (1993a, 1994). Figure 1 shows that a good jumper is able to obtain a high angular velocity at the hip joint and still maintain his upper body in the proper

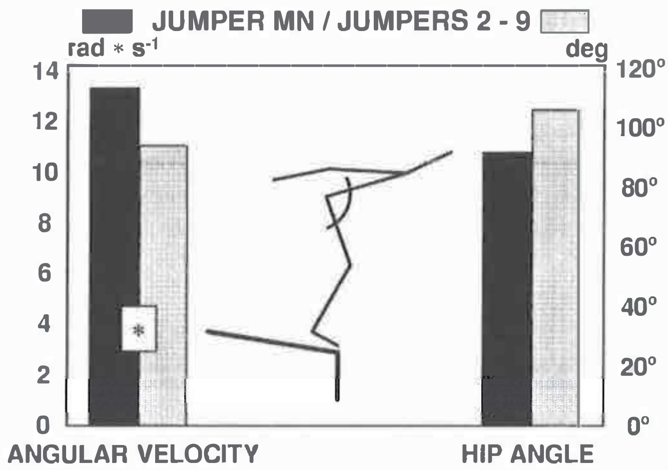


FIGURE 1 Comparison of the angular velocity and the angle of the hip joint between champion jumper MN and jumpers placed 2 – 9 in one competition (Virmavirta 1999).

aerodynamic position.

Better jumpers have been reported to initiate the movement closer to the take-off edge (Komi et al. 1974). Watanabe (1989) examined the timing of take-off under simulated laboratory conditions by dropping a steel ball in front of the jumpers, who were requested to initiate their take-off just as the ball touched down. When the jumpers concentrated mainly on timing, the take-off power decreased by 59 %, whereas the timing errors increased by nearly 30 % when the jumpers aimed for timing plus maximum power.

The somersault angle, defined as the angle between a line connecting the knee and shoulder joint centre to the global longitudinal axis, has been used to describe the production of forward momentum in ski jumping take-off (Arndt et al. 1995). A greater angular velocity facilitates preparation for flight position as rapidly as possible from take-off. Evidence has been presented that more successful jumps are characterised by higher knee extension velocities and simultaneously by a more rapidly decreasing somersault angle towards the take-off edge (Arndt et al. 1995).

2.2 Forces acting on the jumper during take-off

Figure 2 shows all the forces acting on the jumper during take-off together with the conditions necessary for the creation of the angular momentum during take-off (Ward-Smith and Clements 1983, Virmavirta 1999). The first take-off movements are initiated during the transition phase from the end of the inrun curve to the flat take-off table (~ 6 m) (Schwameder 1993, Virmavirta and Komi 1993a). This phase is crucial for the timing and co-ordination of movements, due to the sudden disappearance of the centrifugal force ($mv^2 * r^{-1}$) at the end of the inrun curve. Force measuring systems covering the entire take-off table and the end of the inrun curve also make it possible to determine the centrifugal forces (fig. 3, Virmavirta 1993).

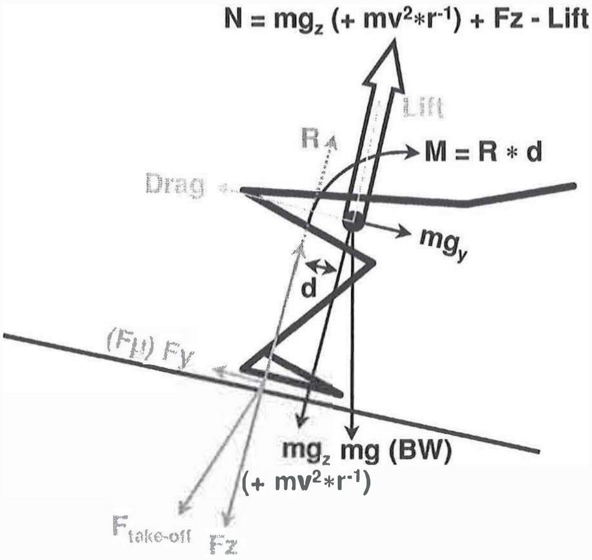


FIGURE 2 Forces acting on a ski jumper during take-off. To obtain maximum height the jumper's centre of mass (CM) should be located along the line of action of the vertical ground reaction force, whereas the production of angular momentum (M) requires the CM to be located anterior to this line (Virmavirta 1999).

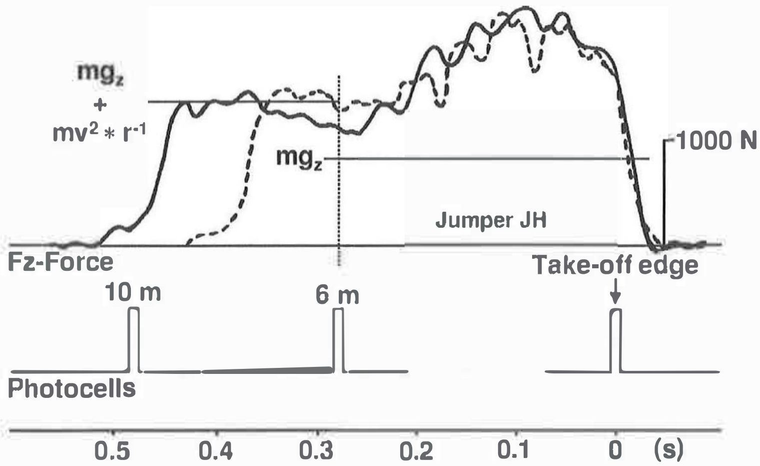


FIGURE 3 Two force curves from the same jumper in two different experiments (1988 solid line, 1991 dotted line) covering respectively the last 10 and 8 meters on the take-off table; mg_z refers to the normal component of the jumper's body weight and $mv^2{*}r^{-1}$ to the centrifugal force (Virmavirta 1993).

2.2.1 Take-off forces

The take-off forces during ski jumping have been measured by several authors either in take-off simulations in the laboratory (Hochmuth 1958-59, Komi et al. 1974, Dillman et al. 1980, Watanabe 1981; 1989, Tveit & Pedersen 1981, Pedotti et al. 1987, Vaverka, for review see 1987, Tsumiyama et al. 1988, Ray et al. 1991, Vaverka et al. 1993, Sasaki et al. 1995, Schwameder et al. 1997) or in actual ski jumping conditions (table 1).

TABLE 1 Force measurements made under actual ski jumping conditions.

Author	Year	Place	Transducer type	Inrun conditions
Sobotka & Kastner	1977	Seefeld (AUT)	force plate	snow
Troxler & Rüegg	1979	St. Moritz (SUI)	force plate	snow
Tveit & Pedersen	1981	Hurdal (NOR)	ski binding	snow
Virmavirta	1988	Jyväskylä (FIN)	force plate	snow
Vaverka	1987	Frenstat p.R. (TCH)	force plate	plastic
Virmavirta & Komi	1989	Calgary (CAN)	force plate	snow
Jost	1993	Oberwiesenthal (GER)	force plate	plastic
Virmavirta & Komi	1993	Jyväskylä (FIN)	force bar	frost rail
Virmavirta	1993	Jyväskylä (FIN)	force bar	frost rail
Schwameder & Müller	1995	Stams (AUT)	EMED insole	porcelain
Yamanobe et al.	1997	Hakuba (JPN)	force bar	porcelain
Yamanobe & Watanabe	1999	Hakuba (JPN)	force bar	porcelain

2.2.2 Take-off aerodynamics (lift and drag forces)

The classic wind tunnel experiments of Straumann (1955) have provided basic information on the aerodynamics of ski jumping. Since then, wind tunnel studies on ski jumping have concentrated on the flight or inrun phase in static situations, and have considerably improved understanding of the effects of aerodynamic lift and drag forces on jumping performance (e.g. Tani and Iuchi 1971). However, due to the ballistic features of ski jumping take-off, the role of aerodynamics during take-off has been discussed but not documented. The difference found between a jumper's vertical take-off velocity as calculated from film analysis and from the net take-off force actually measured has been explained by aerodynamic factors (Virmavirta and Komi 1993a). Schwameder and Müller (1995) measured the normal force component of ski jumpers during the straight part of the inrun; the result, which was 20 % lower than expected, was explained by aerodynamic lift (Baumann 1979, ca. 40 N). However, in practice the lift is negligible during the inrun (Ward-Smith and Clements 1983). Moreover, the take-off times measured in simulated laboratory conditions (chapter 2.1.1) do not match the short take-off time in actual ski jumping conditions (0.25 – 0.30 s, Virmavirta and Komi 1993b) and thus laboratory tests may not correctly describe true take-off performance.

2.2.3 Plantar pressure distribution

A well-balanced inrun posture is vital for a good take-off in ski jumping (Komi and Virmavirta 1997). To obtain a good flight position (i.e. forward leaning), jumpers need to create proper angular momentum during take-off. This involves some requirements for the anteroposterior balance of the jumper's initial position (Arndt et. al. 1995, Komi and Virmavirta 1997).

For dynamic measurement of the movement from inrun to landing, Schwameder and Müller (1995) used two EMED-insoles (sampling frequency 40 Hz) with 85 capacitive sensors each. The ground reaction forces were derived from sensor data using the interpolation method. The study described and analysed the forces in general, as well as in defined parts of the foot and in the points of impact. The results showed an average force value of 66 (±5) %BW for the straight part of the inrun. This force value was approximately 20 % lower than the expected normal force and the authors considered the effects of the shoeshaft, the aerodynamic lift and the systematic error of the measuring system to be the reasons for the difference. During the inrun curve the highest force values were approximately 160 %BW, and the maximum take-off forces were 183 (±8) %BW found 136 ms before the release instant. Comparison between the fore and heel portion of the foot showed that during the straight part of the inrun the force under the heel was slightly higher, while during the curve and take-off the fore foot force was much higher. Furthermore, the forces under the inner part of the foot were about 30 % higher than under the outer part during the entire inrun phase.

2.3 Simulated and actual ski jumping take-off

The number of take-off trials in one ski jumping session is fairly low; thus, in order to overcome the problems involved in ski jumping take-off, ski jumpers utilise simulated take-offs in their training. These simulated take-offs in the laboratory or in training have been designed to mimic real ski jumping take-off as closely as possible. The first comprehensive studies of take-off simulation were done by Hochmuth (1958-59). Some later studies have been presented by Schwameder et al. (1997) with an emphasis on the different aerodynamic and friction conditions between real and simulated ski jumping take-off. Only a few comparisons between real and simulated ski jumping take-offs have been reported (Tveit and Pedersen 1981, Vaverka et al. 1993).

Tveit and Pedersen compared the forces measured from take-off simulations with the forces measured from actual performance on the 70-m hill. They found that the total force was far less on the 70-m hill than in the take-off simulations and thus they concluded that too much attention has been paid to vertical acceleration in take-off. Subsequently, results from a more accurate force measuring system have shown that the forces exerted perpendicularly to the take-off table have an effect on the length of the jump (fig. 4) (Virmavirta and Komi 1993b).

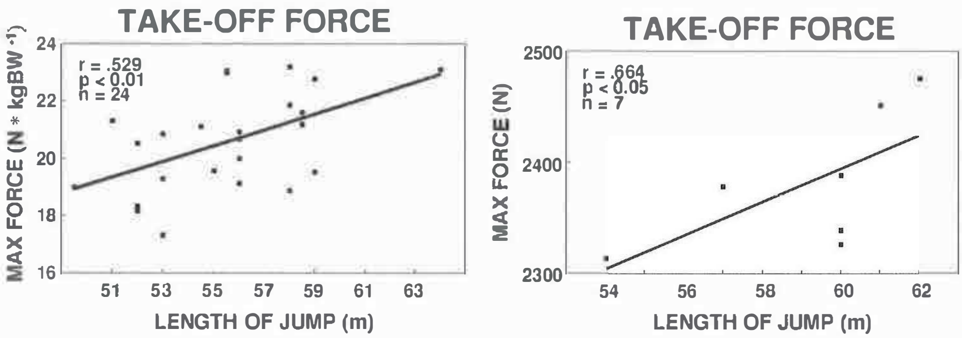


FIGURE 4 Relationship between the maximum normal force and the length of the jump among a group of ski jumpers (left) and for one individual jumper (right) (Komi and Virmavirta 2000).

Comparison of the ski jumping take-off under hill and laboratory conditions has shown that the differences between these conditions are not large. Based on the measurement of take-off forces (Vaverka et al., 1993) the quality of the take-off under hill conditions has been expressed as a percentage of the take-off under laboratory conditions. In the hill conditions the jumpers produced an average of 72 % of the take-off velocity measured in the laboratory. The authors also calculated the theoretical take-off velocity (85 %) without the mass of the skis, and they considered this figure to represent the actual level of take-off ability in real hill conditions. Due to the high relationship between the results for the take-off under laboratory and hill conditions (r = 0.87 and 0.89) the authors concluded that the laboratory take-off is a reliable test for the take-off capacity of ski jumpers.

Simulation take-offs have usually been performed with training shoes and thus they probably differ in regard to the movement patterns occurring with the competition footwear. Stiff ski jumping boots may limit the effective use of the plantar flexors during take-off (Virmavirta and Komi 1991). It has been shown that in a push-off without plantar flexion, as is the case in speed skating (with conventional skates), one is not able to fully extend the knee during push-off (Ingen Schenau et al. 1987). Schwameder et al. (1997) examined this possibility by comparing take-offs performed with training shoes and with jumping boots. When training shoes were worn, the take-off duration was 4.8 % ($p < 0.01$) and the take-off velocity 4.3 % ($p < 0.01$) greater than for the take-off with jumping boots. This difference was explained by the limited plantar flexion with jumping boots, as the duration and amplitude of utilisation of the m. gastrocnemius (IEMG) was significantly higher with training shoes. The authors concluded that the jumping technique depends on the footwear used in certain important respects, and that the use of jumping boots is an essential requirement for technique-specific training in ski jumping.

2.3.1 Different friction conditions

Watanabe (1989) examined two different friction conditions (μ = 1.0 and 0.03) between real and simulated ski jumping take-off. He found that jumpers with roller skates produced their maximum take-off power at an angle of 85° in the low friction condition. Based on an earlier observation that jumpers produced a take-off angle of 45° in simulated take-offs (Watanabe 1983) it was concluded that it might be important to pay more attention to the mental image of athletes for training, even if there is a difference between this image and scientific observation.

2.4 Use of electromyography during ski jumping

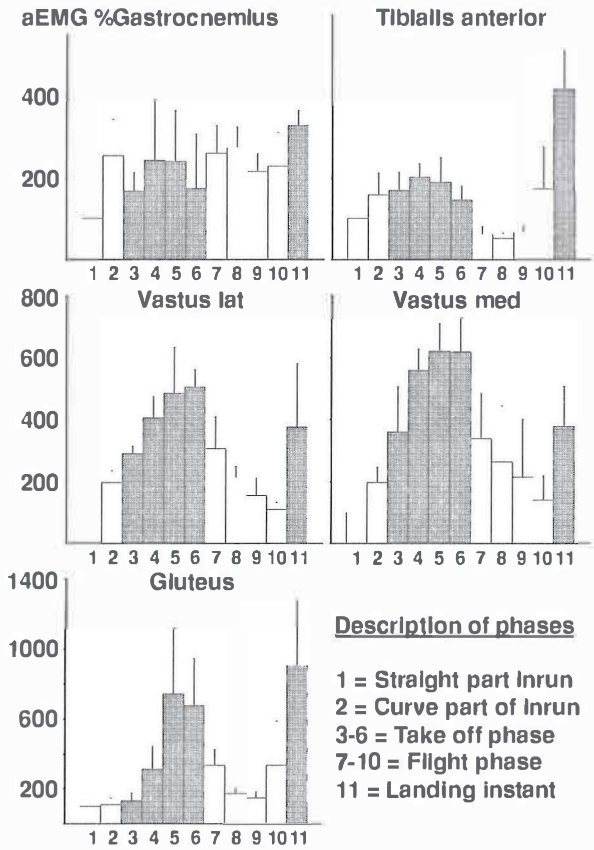


FIGURE 5 The aEMG activities of four muscles in a group of jumpers taken from different phases of the ski jumping performance. The EMG levels are expressed as relative values (%), i.e. the activity measured during the straight part of inrun (phase 1) was given a value of 100 % and the other phases were then related to it (modified from Virmavirta and Komi 1991).

Only a few electromyographic (EMG) studies of ski jumping have been reported (Watanabe et al. 1972; Virmavirta and Komi, 1991; Schwirtz et al. 1996). In these measurements the main concern has been to describe certain muscle activities during the execution of a jump. Figure 5 shows the mean integrated EMG activities for a group of jumpers in the different phases of a jump. From these illustrations it can be observed that it is the leg extensor muscles that are mainly responsible for the execution of the take-off. Strong action in the hip joint is demonstrated by an increase in the activity of the gluteus muscle at the end of the take-off. As is characteristic of take-off in ski jumping, the gastrocnemius muscle (GA) is only weakly active. The utilisation of the GA, especially during the last phase of take-off, is very different from the take-off action in vertical jumps, where plantar flexion is of importance. The quick lifting of the skis does not allow effective use of the GA (i.e. plantar flexion) and thus the take-off is performed more with the knee extensor muscles. On the other hand, the structure of the ski boot actually limits the possibility for efficient plantar flexion during take-off. On the basis of these facts, it appears that the use of training shoes in simulated take-offs may have a negative transfer to real performance (Virmavirta and Komi 1991).

3 THE PURPOSE OF THE STUDY

The general purpose of the present study was to characterise the factors which could limit the execution of an effective take-off in ski jumping. High speed and pressure during the inrun curve as well as aerodynamic factors (drag and lift forces) place special demands on the neuromuscular system of ski jumpers and may therefore belong to these limiting factors. The detailed purposes of the present study can be categorised as follows:

(1) Due to the fairly extreme conditions in ski jumping certain requirements are also placed on data collection. The Paromed Datalogger® system has been used in several experiments in this study. It was therefore important to test whether the system was in fact adequate for obtaining EMG recordings and measurements of plantar pressure distribution in ski jumping.

(2) The different profiles of ski jumping hills with different radii of the inrun curve have been thought to make the initiation of take-off difficult especially when jumpers move from one jumping hill to another. Because the take-off action determines the initial ballistic and aerodynamic factors, which in turn affect the subsequent flight phase, it is important that jumpers should be able to repeat their take-off as well as possible, regardless of the size or profile of hill. One purpose of the present study was to examine the muscle activation patterns and plantar pressures occurring during take-off on three hills of different sizes.

(3) The number of take-off trials in one ski jumping training session is fairly low; thus, in order to overcome the problems involved in ski jumping take-off, ski jumpers utilise simulated take-offs in their training. These simulated take-offs in laboratory or dry land training are intended to mimic actual ski jumping take-offs as closely as possible and it is therefore important to know the similarity between

simulated and real take-offs. The present study attempts to characterise the similarity of these take-offs with regard to plantar pressure and muscle activation patterns. The effect of ski jumping boots on jumpers' take-off capacity was also examined.

(4) Because take-off primarily involves ballistic features, the role of aerodynamics during take-off has been discussed but not documented. Wind tunnel experiments may be utilised in this regard, and therefore a special purpose of this study was to examine the effect of aerodynamic forces on the force-time characteristics of simulated ski jumping take-offs performed in a wind tunnel.

4 RESEARCH METHODS

4.1 Subjects

A total of 19 ski jumpers participated in the various experiments in this study. There were several Olympic winners and World champions among the subjects and seven of them had won at least one World Cup competition.

4.2 Experimental design

This study consisted of the following four experiments: **(I)** a test of the Paromed Datalogger® system, **(II)** examining EMG activation and plantar pressures occurring during ski jumping take-offs on three hills of different sizes, **(III)** a comparison between simulated and actual ski jumping take-offs, and **(IV) the** aerodynamics of ski jumping take-off in a wind tunnel.

4.2.1 Paromed Datalogger® system

The Paromed Datalogger® system was used for measurements of plantar pressure distribution and EMG activation in all four experiments. The Paromed Datalogger® with two insole pressure transducers (16 sensors each, fig. 6) is a logical extension and further development of the Parotec System® manufactured by the Paromed Company. It is a 40 channel data-recording unit (weight 570 gr.) with 32 channels dedicated to pressure sensors and eight universal channels for analog input from other measurement systems (e.g. EMG). The core of the pressure measuring sensors consists of water-filled hydrocells in which an absolute measuring piezoresistive microsensor is embedded. The circuit on the microsensor is a Wheatstone bridge, and the sensor is considered to be self-compensating against temperature effects. The layout of the arrangement of the 16 measuring sensors was designed to measure pressure at the most relevant areas of the plantar surface, based on the testing of approximately 350 subjects (Schumacher 1995). In addition, the manufacturer claims that load distribution tests based on a high-resolution system were used to evaluate the number of sensors needed without losing important pressure distribution data. The results were analysed and optimised based on orthopaedic engineering practices (i.e. the lowering of the longitudinal arch, the loading of Metatarsals II/III etc.).

The Paromed Datalogger system uses pre-gelled single use ECG electrodes (Ag/AgCl, 10 mm diameter and 25 mm interelectrode distance, manufactured in the EU by Niko Surgical Ltd, UK). Electrodes were placed longitudinally on the surface of the muscle belly. The pre-amplification factor in the vicinity of the electrodes is set by manufacturer at 100 and the input impedance at 10 GΩ. The final EMG amplification was set at 1000 with low and high cut-off frequencies of 10 Hz and 400 Hz, respectively.

4.2.2 High speed video recording

Two-dimensional high-speed video recordings (Peak Performance, 100 Hz) were performed for selected motion analysis. The mechanical model of the jumper consisted of 8 segments (head, trunk, thigh, shank, foot, arm, forearm + hand) and was used mainly to characterise possible differences in movement patterns between the take-off positions with training shoes and jumping boots in experiment III, and between the non-wind and wind conditions in experiment IV.

4.2.3 Experiment I

The Paromed Datalogger® was applied to study the feasibility of the system for measurement of plantar pressure distribution in ski jumping. Three international level ski jumpers served as subjects during the testing of the system. In the present study, the Datalogger information was synchronised with three photocell signals using a separate pulse which was transmitted to the logger and tape recorder simultaneously. A telemetric unit (Medinik AB) was used to detect, transmit, and receive the sync pulse on the taperecorder. Photocell (Newtest Ltd.) signals indicating the location of the jumper on the inrun were also transmitted and recorded. To illustrate the utility of the Datalogger for collecting other relevant analog signals, muscle activation of the primary take-off muscles was recorded with the same Paromed unit, which was remote controlled and attached to the jumper's waist under the ski jumping suit. EMG data was not further analysed in this experiment. The sampling frequencies were 200 Hz for pressure and 800 Hz for the EMG and the synchronising pulses. The pressure distribution under the feet was examined mainly in the anteroposterior (toe/heel) direction. Figure 6 shows that the pressure was almost entirely distributed on sensors 1-2 and 15-16. The pressure contours in figure 6 were generated using the NURBS-method (Non-Uniform Rational B-Splines presenting method, Kokkonen 1999) at the Silicon Graphics workstation. The signals from two pressure sensors, the four EMG channels, and the synchronising pulse are shown in figure 7 and provide an example of a typical Datalogger recording.

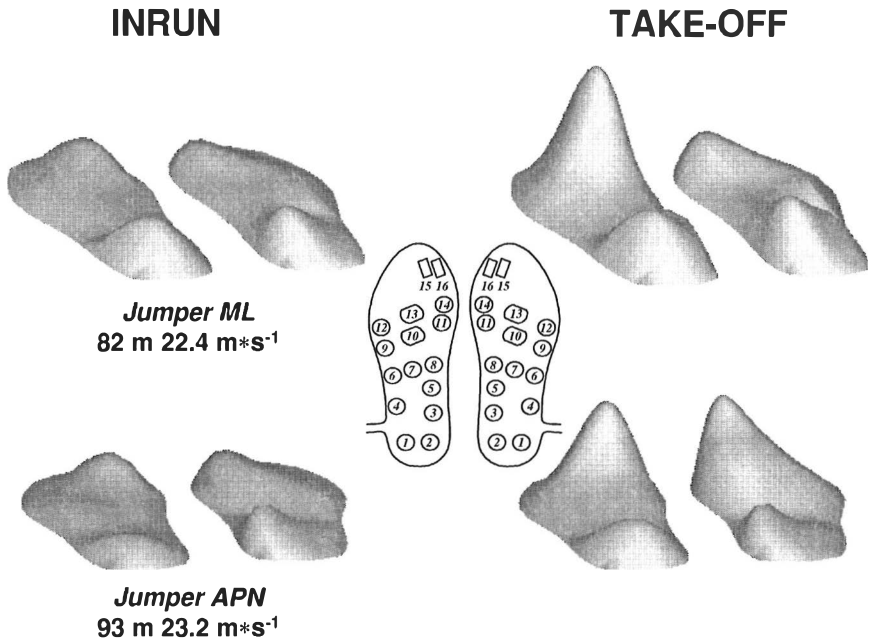


FIGURE 6 Examples of the pressure contours from two different jumpers (ML and APN) during the inrun and take-off phases. The sensor locations on the pressure insoles are also shown.

The system validity was roughly estimated by comparing the relative increase in pressure at the beginning of the inrun curve with the calculated relative centrifugal force (mv^2*r^{-1}). The pressure values recorded during the inrun curve phase were expressed as a percentage of the baseline values (100 %) measured before the inrun curve. The calculated centrifugal force values for the given radius of the inrun curve (90.6 m, Certificate of Jumping Hill No. 63/FIN 3) ranged from 56 to 61 % of the jumpers' bodyweight, based on the masses (61.4 – 64.6 kg) and the speeds (22.3 – 23.4 $m*s^{-1}$) used in this experiment (K – 90 m hill). The percentage change in pressure was finally contrasted with the centrifugal force calculated as a percentage of the baseline condition (100 %). On this basis, the calculated force range was 156 - 161 %. Furthermore, the decrease in inclination of the inrun tracks along the curve (35° > 10°) caused the normal force component (Fz) to increase by 20.2 % at the end of the curve.

The main contribution of the pressures comes from sensors 1 and 2 (heel area) and 15 and 16 (toe area). Using these sensors the anteroposterior balance of the jumpers' inrun posture was examined in more detail. The increase in pressure caused by the take-off action was taken to be as the change of pressure from the inrun to the take-off phase, for the heel and the toes, separately.

The pressure values reported in this study are the mean values during the time intervals selected. The inrun values are from the straight part of the inrun (1 s). The inrun curve was divided into three phases (300 ms each) covering the early, mid and final phases of the curve. The take-off was divided into five separate time intervals of 50 ms.

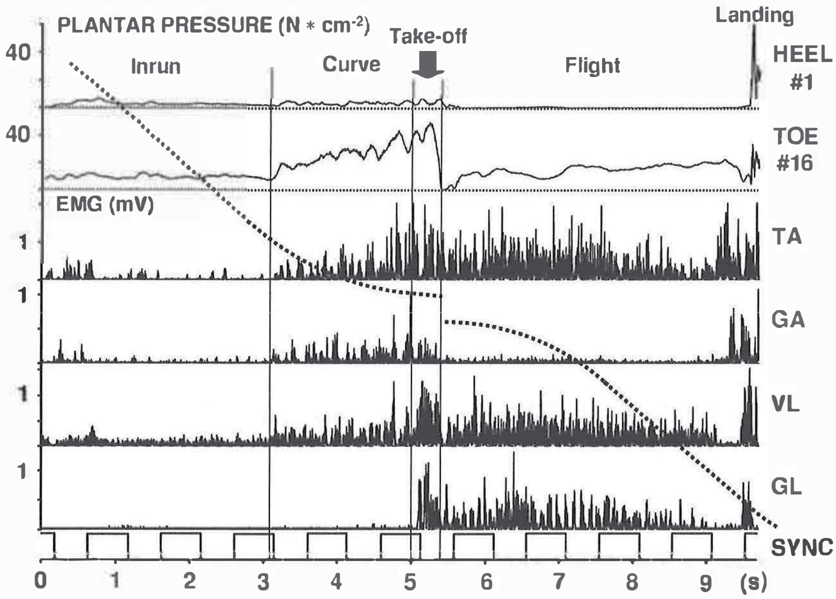


FIGURE 7 An example showing pressure, EMG (TA tibialis ant., GA gastrocnemius, VL vastus lat., GL gluteus) and sync pulse curves from one jump with inrun speed 25.5 $m*s^{-1}$ and length of jump 113 m.

4.2.4 Experiment II

The neuromuscular adaptation of the ski jumpers to the different jumping hills was examined by measuring the muscle activation and plantar pressure (Paromed Datalogger®, see Exp. I) of the primary take-off muscles (VL – vastus lateralis, GA – gastrocnemius, TA – tibialis anterior, BF – biceps femoris and GL – gluteus) on three differently- sized hills. Two young ski jumpers volunteered as subjects and they performed several trials on each hill (K – 35 m, K – 65 m and K – 90 m) with the same EMG electrode and insole pressure transducer set-up. The subjects were assumed to be able to exert their full take-off capacity on all the hills used. This subject selection was based on the common practical knowledge that the more ballistic conditions on small hills cause some problems for those jumpers who are used to jump and train only on larger hills which have greater aerodynamic requirements. Given these facts, the number of subjects suitable and available for this particular comparison is very limited. In addition, the protocol used in this study including the shift from one hill to another, made it possible to study only two subjects with 2 – 4 trials on each hill per day. It is very difficult to find a testing day with the same weather conditions throughout the measurements. These requirements naturally limit the use of large numbers of subjects and consequently the use of normal statistical procedures. Nevertheless, the same measurement procedure was repeated with one additional jumper in a separate experimental session on K – 65 m, K – 90 m and K – 116 m hills.

The average pressure (N*cm^{-2}) and aEMG (mV) values were calculated for different phases (1 – 5, fig. 8) of the jump with Paromed DLS software. The take-off was divided into three separate time intervals (phases 3, 4 and 5, 100 ms each). The mean values for the inrun (phase 1, 500 ms) were taken from the middle part of the straight inrun, and the inrun curve (phase 2) values covered the 300 ms of the phase where no take-off movement was involved. To allow a comparison with muscle activation during take-off, the inrun phase 1 was set to correspond to 100 % (see fig. 5) and phases 2 - 5 were related to it according to our previous method (Virmavirta & Komi, 1991). It was thought that this method would make it possible to average the EMG values of the different subjects and perform subsequent intermuscular comparisons. This method gives the knee extensors lower relative activities than would be expected even though they are regarded as the main take-off muscles.

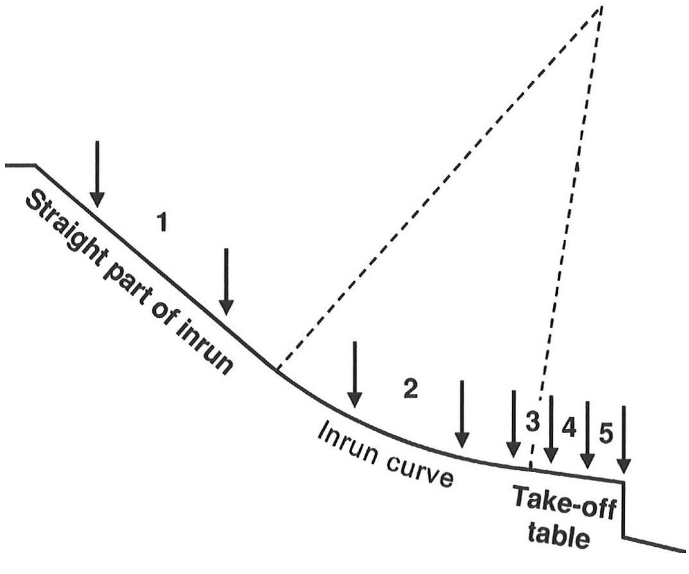
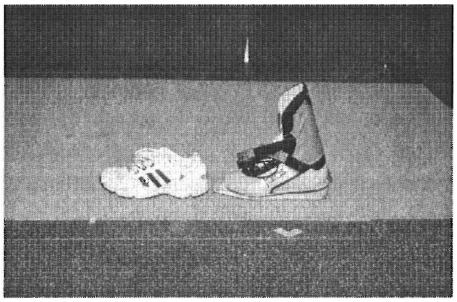


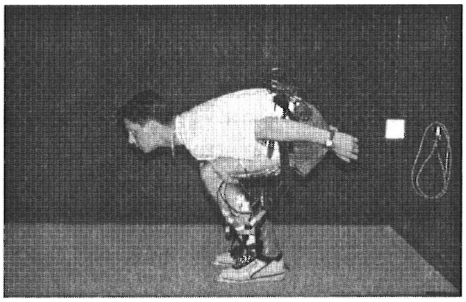
FIGURE 8 Average pressure and EMG (aEMG) values were calculated for the five separate phases of the inrun.

4.2.5 Experiment III

Plantar pressures and the activation of four muscles (VL - vastus lateralis, GL - gluteus, TA - tibialis anterior and GA - gastrocnemius) were measured from ten ski jumpers (including two Olympic winners and one World champion) in simulated laboratory conditions, with training shoes (LabTS) and with jumping boots (LabJB) as well as in actual hill conditions (Hill). The vertical (Fz) and horizontal (Fy) take-off forces were also recorded in laboratory measurements.

The subjects performed 12 trials with each of the sets of footwear, with the same EMG electrode and pressure insole set-up. Hill measurements (K – 100 m, inrun speed 23 – 24 m*s^{-1}) were performed immediately after the simulated take-off, again with the same EMG electrode and pressure sensor set-up.





The force analysis consisted of force production times and maximum forces for both Fz and Fy. Take-off velocities (v_z and v_y) were calculated on the basis of net force impulses (the impulse due to the ground reaction force after subtraction of body weight in v_z) according to the following formulae:

$$NI\ (\,net\,impulse\,) = \int_{t_0}^{t_1} [\,F(\,t\,) - mg\,]\,dt \quad [1]$$

$$NI = \int_{t_0}^{t_1} [\,F(\,t\,) - mg\,]\,dt = mv_1 - mv_0, (\,v_0 = 0\,) \quad [2]$$

$$v_1 = F(\,t\,) - mg\,/\,m \quad [3]$$

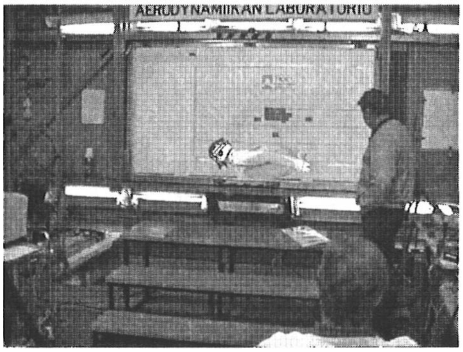
Velocities were then used for calculation of the take-off angle:

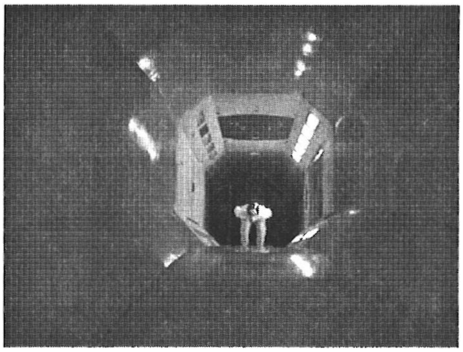
$$Take-off\ \ angle = A\,tan v_z\,/\,v_y \quad [4]$$

The average pressure (N*cm^{-2}) and aEMG (mV) values were calculated for the different phases (see fig. 8) of the take-off using the Paromed DLS software. The take-off was divided into three separate time intervals before the release instant (300 - 200 ms, 200 - 100 ms and 100 - 0 ms). The values of the initial take-position (inrun) were taken from the middle part of the straight inrun under hill conditions, and from the phase where no take-off movement was yet involved in the Lab conditions. In the hill conditions the pressure and EMG values were also taken from the inrun curve phase where the centrifugal force was acting on the jumper but no take-off movement was involved.

Two-dimensional high-speed video recordings were made for selected motion analysis of the initial take-off positions with training shoes and with jumping boots.

4.2.6 Experiment IV





The effect of wind on the force-time characteristics of the simulated ski jumping take-off was measured using two world-class ski jumpers (JA, JS) and one less experienced junior jumper (ML) in a subsonic Göttingen-type closed circuit wind tunnel (Laboratory of Aerodynamics, Helsinki University of Technology, Espoo, Finland). The tunnel cross-section and the maximum speed in the test area were 3.68 m^2 and 70 $m*s^{-1}$, respectively. A low nominal turbulence (0.1 %) in the empty test section was achieved by a large settling chamber with a contraction ratio of 13 and with a main flow velocity distribution of 0.12 %. A Pitot tube connected to a Rosemount pressure meter was used to derive the wind velocity from the kinetic pressure. A Boundary layer and blockage effect correction (correction factor 1.04 including the portion of boundary layer 3.4 %) was done to the measured kinetic pressure by using the well established Maskell's correction methods (Rae and Pope 1984) based on average blockage during take off ($\varepsilon = 0.25*(S*A^{-1})$, where S is blockage area of model and A area of tunnel test section). This allowed the true flow velocity (v) to be calculated according to the following formula:

$$v = \sqrt{2q * \rho^{-1}}, \quad [5]$$

where q is kinetic pressure (Pa) and ρ air density ($kg*m^{-3}$). The air density (ρ) was calculated according to

$$\rho = p*(RT)^{-1}, \quad [6]$$

where p is air pressure (Pa), T air temperature (K) and R gas constant (287.1 $JK^{-1}kg^{-1}$). Vertical and horizontal ground reaction forces were recorded with a force plate installed under the tunnel floor (fig. 9) during ski jumping take-offs in non-wind conditions as well as in conditions with different wind speeds (21 – 33 $m*s^{-1}$). The non-wind conditions served as a reference "laboratory trial" for the other trials in different wind speeds. The take-off situation in wind tunnel was carefully tested before the measurements and jumpers did not find any difficulties while taking off with maximal effort. The wind tunnel floor was softened with the thin mattresses. The jumpers performed the simulated take-offs (4 – 6 in each condition) in the same way as in training. In the reference non-wind condition an assistant was used to support the jumper after toe-off as the take-off was directed up and forward. In order to simulate actual low friction conditions where little or no horizontal (anteroposterior) forces can be produced, one jumper also performed a series of vertically directed take-offs. The aerodynamic lift and drag (air resistance) forces during the initial take-off position (static inrun position) were read from the vertical and horizontal ground reaction forces. The force plate arrangement also enabled the lift and drag forces of the flight simulation without skis to be recorded.

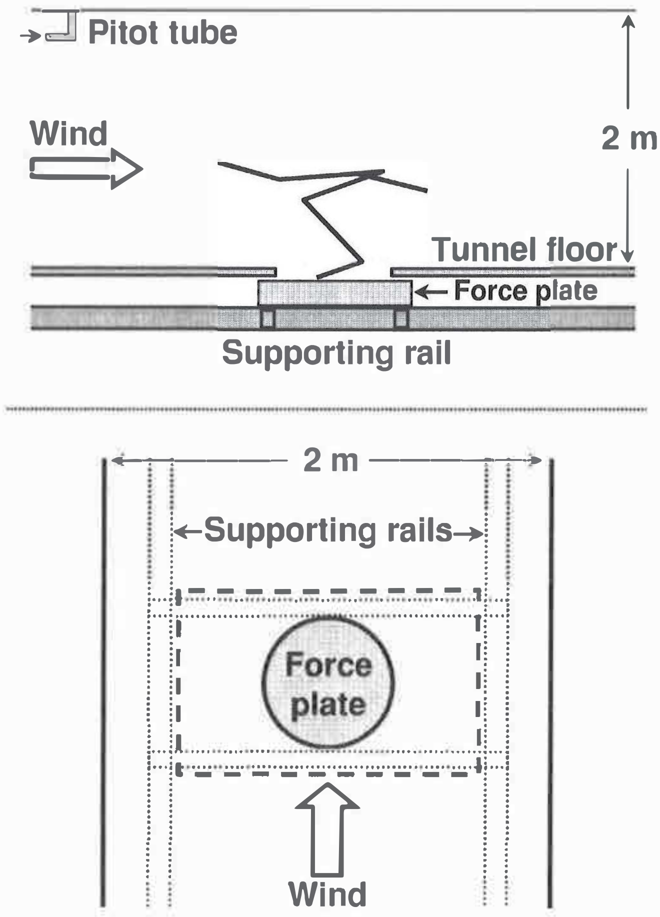


FIGURE 9 Schematic illustration of lateral (upper) and overhead (lower) views of the force plate arrangement in the wind tunnel.

EMG activities from the three selected muscles (Vastus lateralis, Gastrocnemius and Gluteus) of one jumper were recorded by a Paromed Datalogger (see 4.2.1) attached to the jumper's lower back under the jumping suit.

In order to strengthen the observations obtained in the first wind tunnel measurements the same experiment procedure was repeated with greater number of subjects (12 jumpers).

Data processing

The force production time as well as the average and maximum net force levels was analysed from the vertical ground reaction force signals. The average lift force of two jumpers during take-off was calculated by using equations for average acceleration (a) and for average force (F):

$$h = \tfrac{1}{2}at^2 , \quad [7]$$

where h is the vertical displacement of the body center of gravity during take-off and t is the take-off time.

$$F = ma . \quad [8]$$

Thus the difference in average force between the non-wind and wind conditions (27 $m{*}s^{-1}$) can be accounted for the aerodynamic lift force. The air resistance of the initial take-off position (i.e. static inrun position) was read from the horizontal force component just before the take-off. The aerodynamic lift force during the same initial phase was calculated from the non-wind conditions as a reduction in body weight. The aerodynamic forces acting on the jumper during forward leaning ("flight position") were also calculable from the ground reaction forces.

In the EMG measurements the average muscle activities (aEMG) were compared between the non-wind condition and the wind condition of 27 $m{*}s^{-1}$. Owing to the possible effect of the Datalogger on the air stream around the jumper ("hunchback") this comparison was done separately from the other trials.

The take-offs were filmed with one high-speed video camera from the side through a window in the tunnel door and recordings were used mainly to characterise possible differences in movement patterns between the non-wind and wind conditions.

Computer simulation

The results were fed into Aquila ski jumping simulator. The Aquila is a time discrete 2^{nd} order CoG-point simulator modelling the complete ski jumping performance: the inrun, take-off, transition to flight and flight. The time step used in the simulator was 0.02 seconds. The Aquila simulator has been tested against the Finnish Artillery 6DOF-simulator and found to be very accurate. The following parameters were used as input: Total mass of the ski jumper, reference area of the ski jumper, coefficient of ski friction, take-off force profile with max value, drag (Cd) and lift (Cl) coefficients for the crouch inrun position, and Cd (t) and Cl (t) for the flight phase.

4.2.7 Statistics

Due to the facts mentioned in chapter 4.2.2 the number of subjects suitable and available for this particular study is very limited and thus the use of normal statistical procedures is also limited. However, in some cases analysing individual jumpers repetitively is very probably a better method than trying to collect single jumps from many athletes in same the situation. Note that although there is not necessarily a correlation between some variables when single jumps from many jumpers are examined, the individual jumpers may still have this correlation (Troxler and Rüegg 1979). Ski jumping is a very complex performance and the great variability among the jumpers in the various phases makes the group approach somewhat questionable (good information may be lost). Our previous studies show that we have managed to produce very informative data for practical purposes with small numbers of subjects (Virmavirta and Komi 1993a,b). In those cases where the number of trials is also limited (e.g. Exp. II) a calculation of the CV% would be the only reasonable alternative.

Despite limitations on normal statistical procedures mentioned above, the differences in EMG and plantar pressure between the 3 hills (four trials each) in experiment II could be roughly tested using an ANOVA SPSS analysing program. The analysis was performed in a fairly "forced" manner, for trials not for subjects, and should be interpreted with caution. The coefficients of variability (CV%) between the hills were calculated for the mean values of the trials. The CV% was also calculated for all two successive trials. Selected results from the statistical analysis have been presented in this paper.

The differences between real (Hill) and simulated (Lab) take-off conditions, as well as those between simulated take-off conditions, with training shoes and with jumping boots (Exp. III), were tested using the two-way T-test for samples with equal variance and two-way paired T-test. Because the same electrode placement in different conditions, the statistical significance could be calculated for absolute aEMG values. However, in some cases for better visual comparison between different conditions and muscles, the EMGs are presented as percentages of the actual jumping hill conditions (100 %).

In experiment IV the trials in non-wind conditions were compared with the trials performed in different wind conditions separately for each subject, using the two-tailed T-Test for samples with equal variance.

5 RESULTS

5.1 The use of the Paromed Datalogger® in ski jumping

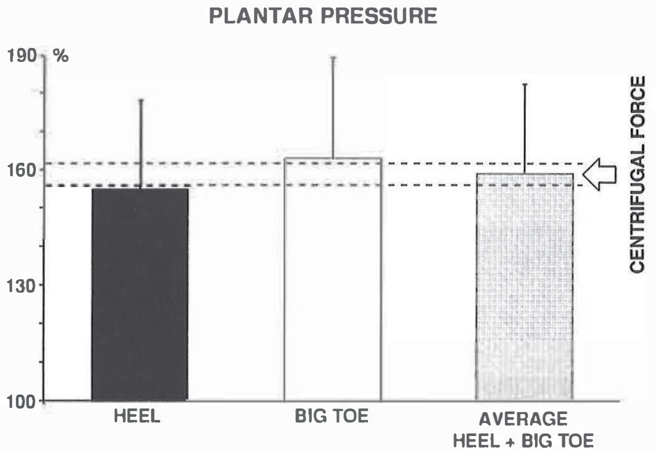


FIGURE 10 Comparison between the measured relative increase in pressure and the calculated (mv^2*r^{-1}) relative centrifugal force at the beginning of the inrun curve. The results are given as a percentage of the baseline condition before the inrun curve (100 %).

A comparison between the measured and calculated (mv^2*r^{-1}) increase in pressure at the beginning of the inrun curve can be seen in figure 10. The measured values were 155 ± 23 % and 163 ± 26 % under the heel and big toe respectively, the average (159 ± 24 %) being in the middle of the calculated relative centrifugal force range (156 – 161 %). The average increase in pressure (toe + heel) during the curve was 14.1 ± 16.9 %. The anteroposterior balance of the jumpers' inrun posture is presented as the relative contributions of the toe and heel pressures (fig. 11). These were, respectively, 62.4 and 37.6 % for jumper APN, 50.2

and 49.8 % for KS, and 45.7 and 54.3 % for ML. The increase in pressures during take-off is also seen in figure 11. Compared with the inrun phase, the pressure values at take-off ranged from 135 ± 8 % to 221 ± 45 % for the heel, and from 191 ± 29 % to 558 ± 42 % for the big toe.

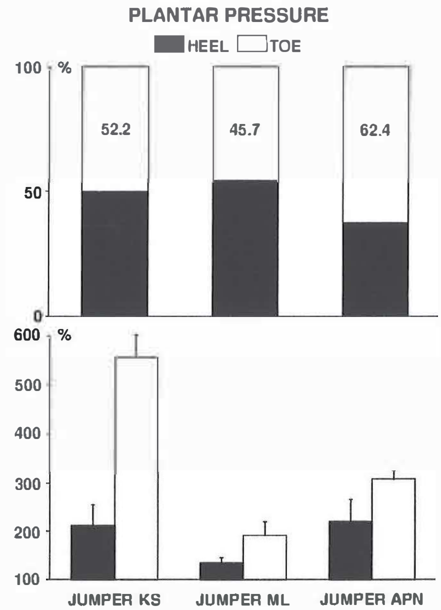


FIGURE 11 Relative contributions of the toe and heel pressures in different jumpers during the straight inrun (upper). Increase in pressure under the heel and big toe during take-off (inrun = 100 %; lower).

5.1.1 Take-off on hills of three different sizes

Some data concerning the jumping hill profiles are presented in table 2, where the velocity and the length of the jump represent the mean values from all the trials.

TABLE 2 Data on the ski jumping hill profiles used in this experiment: the radius of the inrun curve (R) and the length of the take-off table are taken from the hill certificate; the initial velocity (V_0) and the jumping distance (D) are mean values from all the trials.

	K – 35 m	K – 65 m	K – 90 m	K – 116 m
V_0 ($m*s^{-1}$)	16.8	21.1	23.3	25.3
R (m)	41	68	89	95.6
T (m)	4	5.6	6	6.43
D (m)	35	57	72	99

The strong increase in pressure under the big toe at take-off is demonstrated in figure 12. The small deviations show that the pressure differences between the hills were fairly small. The strong contribution of the VL and GL muscles to the take-off action can be seen figure 13. Activation of the GA did not change much during take-off.

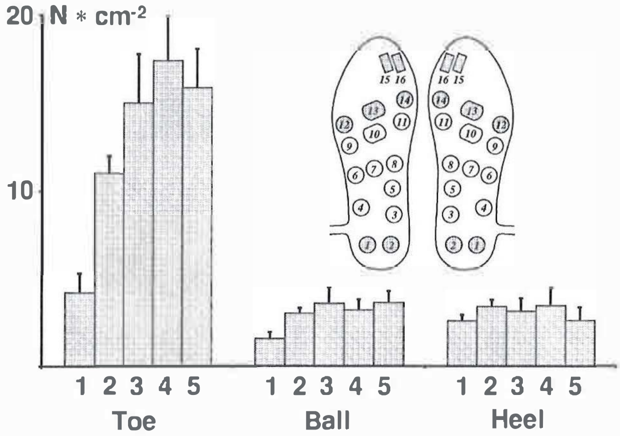


FIGURE 12 Mean average pressure values from all the trials for the selected areas of the foot sole during the different phases of approach (phases 1 - 2) and take-off (phases 3 - 5).

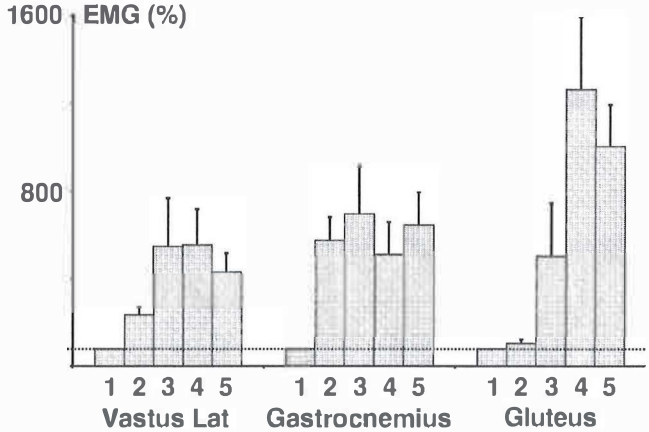


FIGURE 13 Mean average EMG (aEMG) from all the trials during the different phases of approach (phases 1 - 2) and take-off (phases 3 - 5). Phases 2 – 5 were all related to phase 1 (100 %) (for method see Virmavirta and Komi 1991).

Figure 14 shows examples of more detailed changes in pressure during the last 500 ms before the release instant from the take-off ramp. The differences in maximum pressure between the hills were fairly small (25.9 – 26.7 N$*$cm^{-2} for jumper VML, and 24.6 – 33.1 N*cm^{-2} for jumper ML) and the most distinct difference can be found in the rate of pressure production under the toes in the small hill. The differences in EMG between the hills were also very small, as can be seen in the examples from both jumpers (figures 15a and b). The average EMG (aEMG) amplitude for the VL and GL muscles respectively during the last 100 ms of take-off ranged from 0.22 to 0.28 and 0.14 to 0.20 mV for jumper VML and from 0.22 to 0.26 and 0.14 to 0.24 mV for jumper ML over the three hills. The activation of the GL shows also that hip extension was performed with the same timing over the three hills. Similar patterns over the three hills can be seen in the EMGs of the TA and GA muscles.

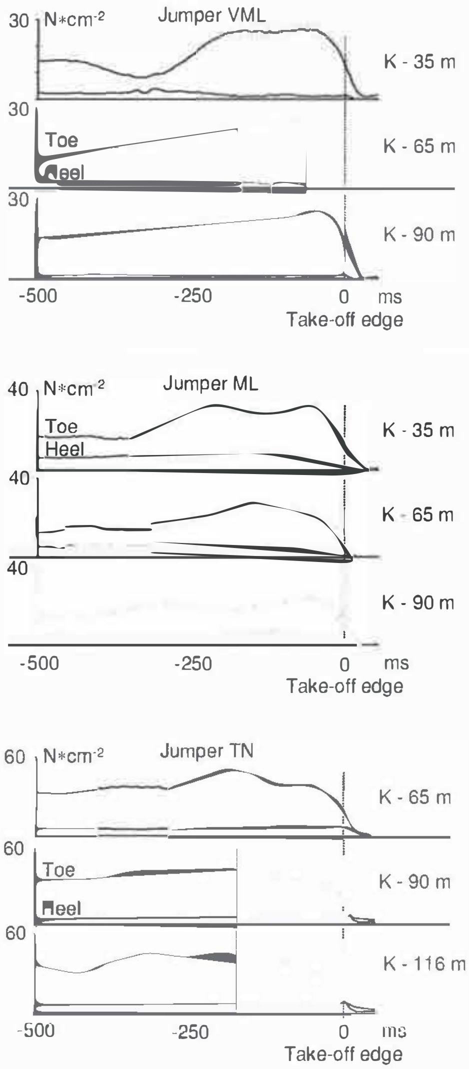


FIGURE 14 Plantar pressure patterns during the last 500 ms before take-off edge on ski jumping hills of three different sizes. Each curve includes 2 – 3 trials from each jumper (VML, ML and TN).

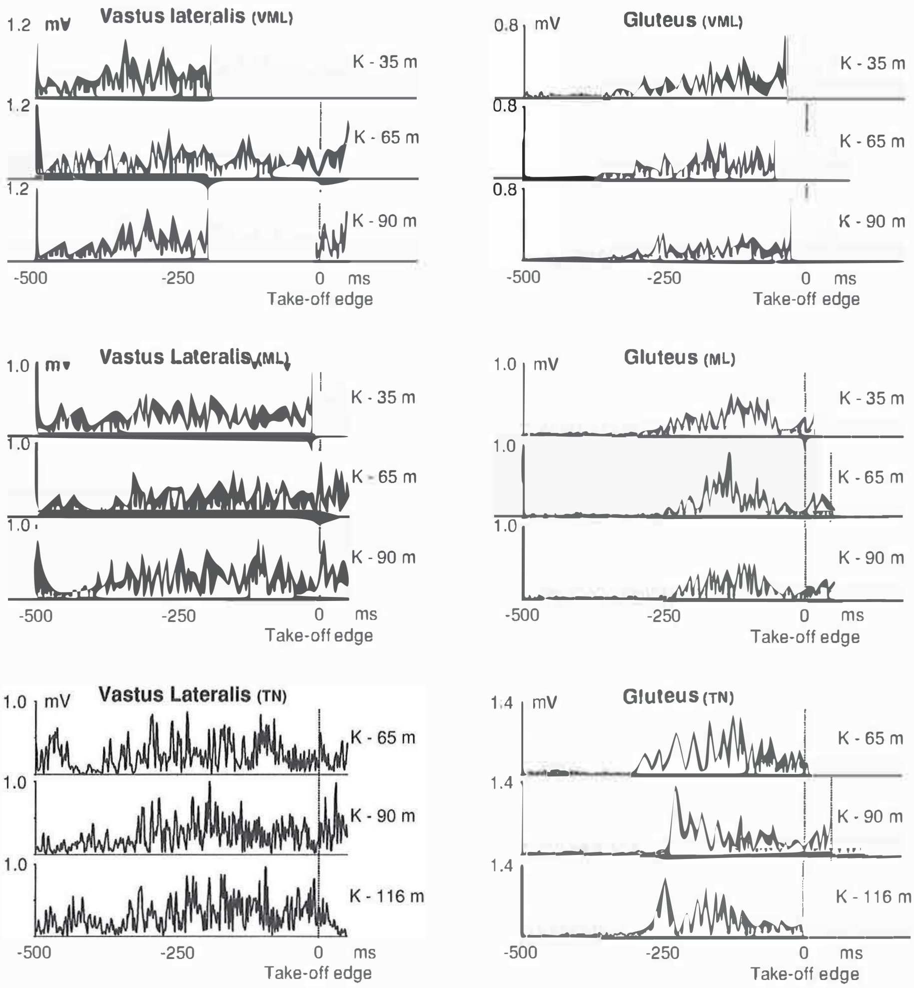


FIGURE 15A The EMG patterns of the Vastus lateralis and Gluteus muscles for the last 500 ms before take-off edge on differently-sized ski jumping hills. Each curve includes 2 – 3 jumps from each jumper.

In general, slightly greater EMG activities and pressure values - especially under the toe area - were found for small hills as compared to larger ones, but only a few of the differences between the hills were statistically significant. No statistically significant differences at all were found between hills K – 65 m and K – 90 m. The significant differences are summarised in figure 16a (EMG) and 16b (plantar pressure). The average coefficients of variability (EMG CV%) calculated from the mean values for each hill of all the various phases and muscles were 8.5 % (35/65 m), 7.7 % (35/90 m) and 5.4 % (65/90 m). The corresponding average percentages for pressures were 12.5, 18.8 and 6.9 %. The CV% for pressure and the EMG of all two successive jumps were 9.9 and 16.3 %, respectively.

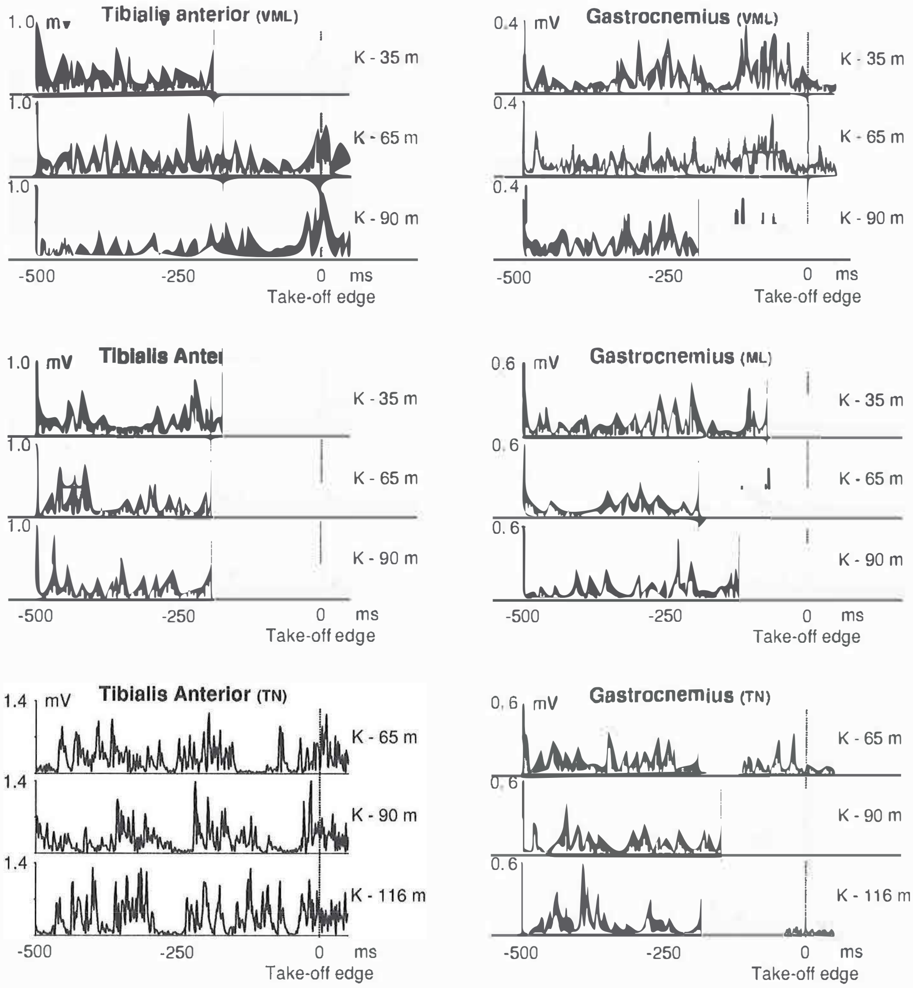


FIGURE 15B The EMG patterns of the Tibialis anterior and Gastrocnemius muscles for the last 500 ms before take-off edge on differently-sized ski jumping hills. Each curve includes 2 – 3 jumps from each jumper.

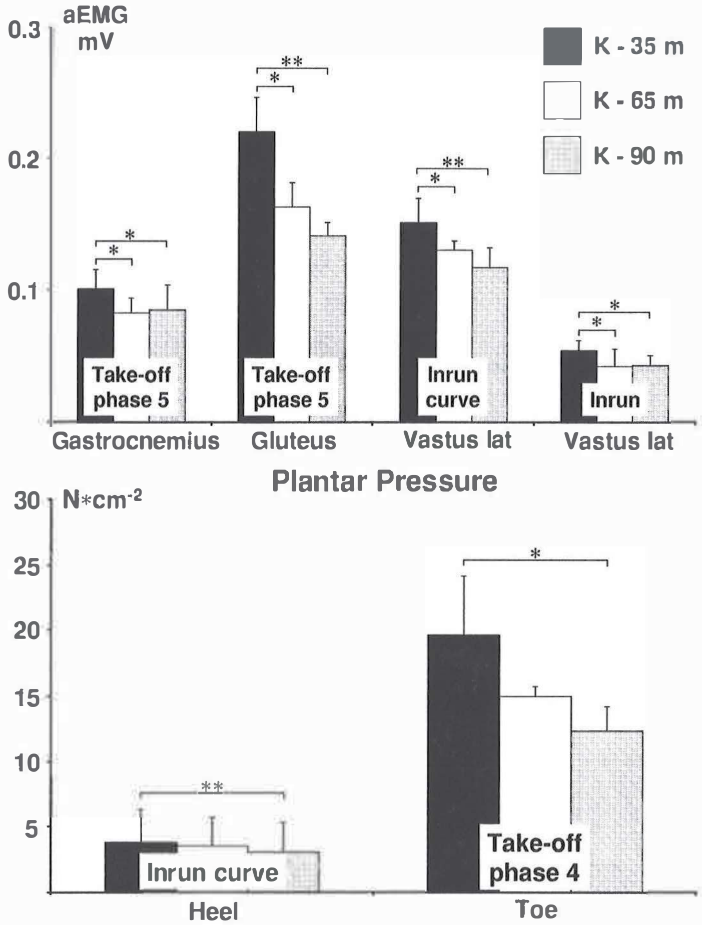


FIGURE 16 Significant differences in EMG measurements (upper) and plantar pressures (lower) between hills.

5.2 Simulated vs. actual ski jumping take-off

The aEMG activities expressed as percentages for different muscles under different conditions are presented in figure 17 (left). The most significant differences ($p < 0.001$ for TA, GA, VL and $p < 0.01$ for GL) in the initial take-off position (inrun, fig. 17a) can be seen between the Lab conditions and the real inrun curve condition. The activities of the TA and GL in the Lab were also lower as compared with the straight inrun phase. The initial take-off position (inrun) showed no clear differences between the conditions with different footwear. During the three take-off phases only the TA and the GA showed significant differences between the conditions. GA activity was significantly higher in the simulated condition during the entire take-off phase. The VL and GL did not show any major differences during take-off.

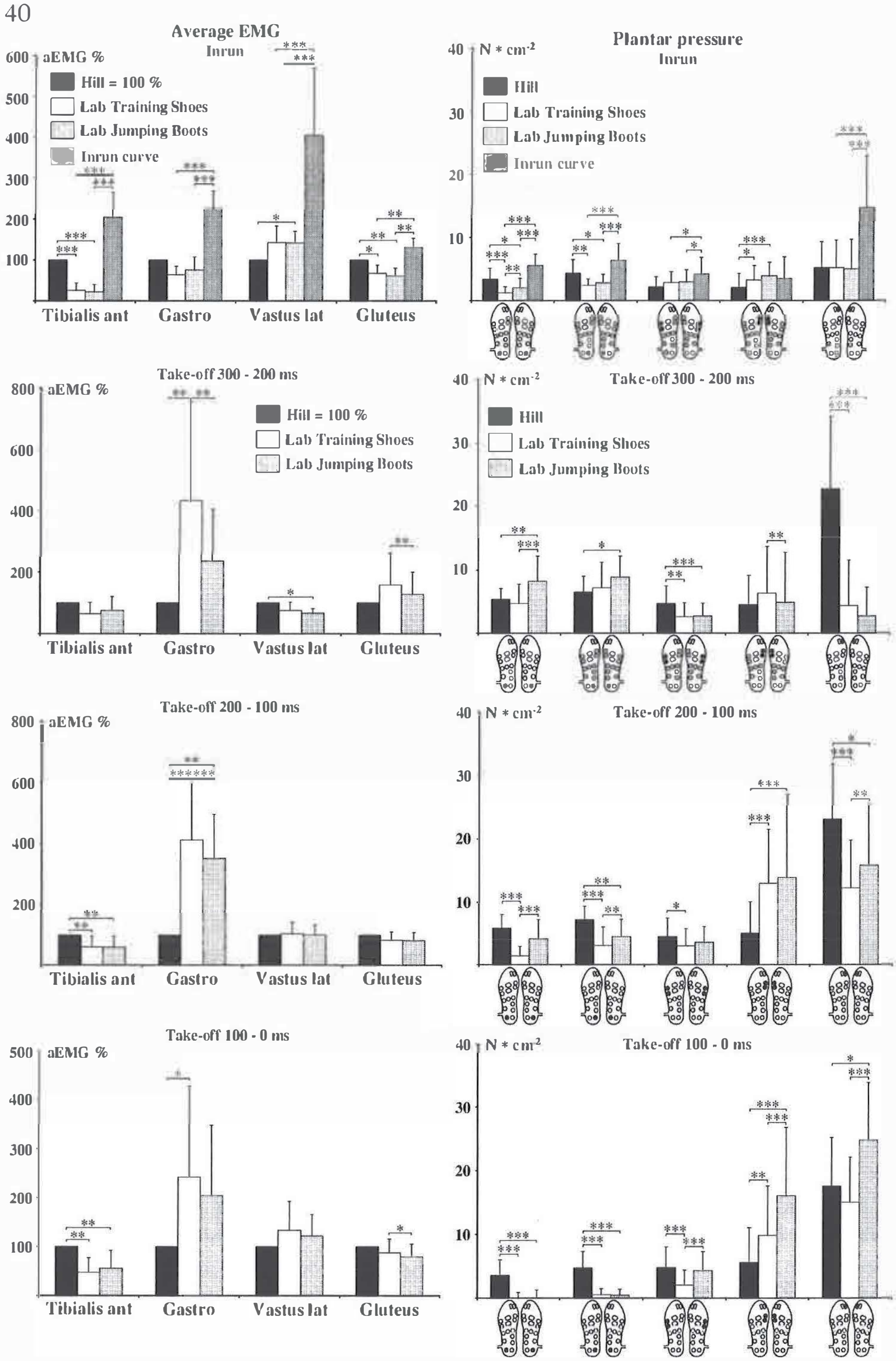


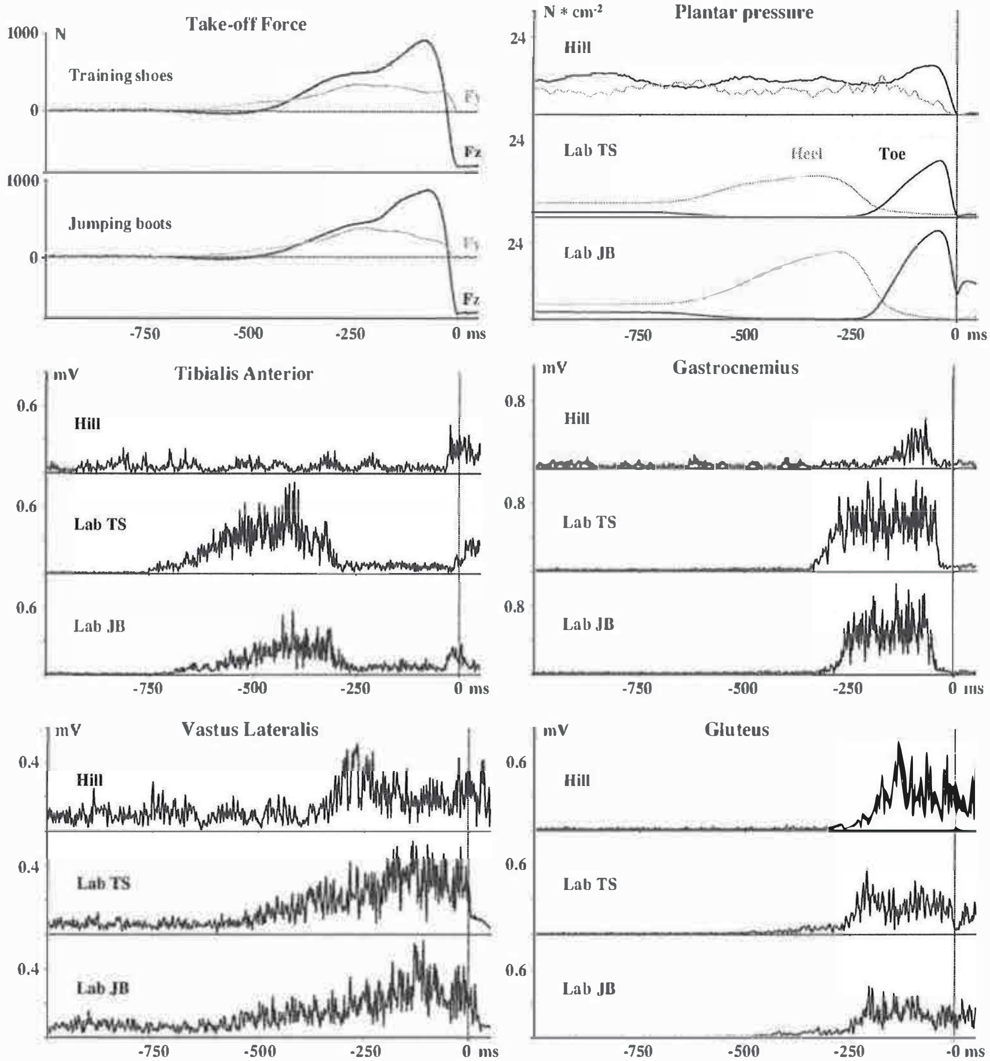
FIGURE 17 Mean (± SD, n = 10) aEMG for different muscles (left) and selected mean plantar pressures (right) from different phases of actual hill take-off (Hill) and simulated take-off in laboratory (Lab) conditions, with training shoes and jumping boots. The EMGs under Hill conditions were given a value of 100 % and measurements under Lab conditions were then related to this baseline.

These small differences can also be seen in figure 18, which presents average EMG patterns, selected plantar pressures (toe/heel) and ground reaction forces (Lab only) from several trials with one excellent jumper during take-off. Significant differences between the conditions during take-off with different footwear were found for the gastrocnemius (300 – 200 ms and 200 – 100 ms before release) and the gluteus (300 – 200 ms and 100 – 0 ms) values being smaller when the jumps were performed with the ski jumping boots. Figure 17 (right) presents plantar pressures from different phases of take-off in different conditions. The pressures during the initial take-off phase (inrun curve) in Hill conditions were significantly higher ($p < 0.001$) under the heel and big toe area as compared to Lab conditions. The straight part of actual hill inrun also produced higher pressures for the heel area. The pressure values under the heel in Hill conditions were especially high at the end of take-off, whereas the medial side of the fore foot was strongly loaded during this phase in Lab conditions. A major difference between the Hill and Lab conditions ($p < 0.001$) can also be seen in the toe pressure at the beginning of take-off. During the early take-off phase (300 – 200 ms) with jumping boots, significantly greater pressure was recorded under the heel area ($p < 0.001$) while the fore foot area was highly loaded at the end of the take-off.

The mean (± SD) take-off force parameters with training shoes and jumping boots are presented in table 3. Significant differences were found in vertical ($p < 0.001$), horizontal ($p < 0.05$) and resultant ($p < 0.001$) velocities as well as in the Fz impulse ($p < 0.01$). Table 4 shows that no differences were found in jumpers' initial take-off positions, but that the final positions differed significantly depending on the footwear used: in the ankle angle ($p < 0.001$), knee angle ($p < 0.001$), hip angle ($p < 0.01$) and shank angle relative to horizontal ($p < 0.01$, see also Fig. 19). The displacements in these cases were smaller with the ski jumping boot.

TABLE 3 Take-off parameters (mean ± SD) with training shoes and jumping boots.

	Training Shoes				Jumping Boots		
Max force, Fz (N)	753	±	163		752	±	148
Take-off time, Fz (ms)	492	±	83		474	±	55
Impulse, Fz (Ns)	151	±	31	**	143	±	30
Vertical velocity ($m*s^{-1}$)	2.38	±	0.28	***	2.18	±	0.29
Max force, Fy (N)	307	±	65		323	±	71
Take-off time, Fy (ms)	722	±	75		706	±	52
Impulse, Fy (Ns)	90	±	23		90	±	22
Horizontal velocity ($m*s^{-1}$)	1.42	±	0.28	*	1.37	±	0.26
Resultant velocity ($m*s^{-1}$)	2.78	±	0.34	***	2.59	±	0.33
Take-off angle (°)	59.2	±	4.2		58.0	±	4.6



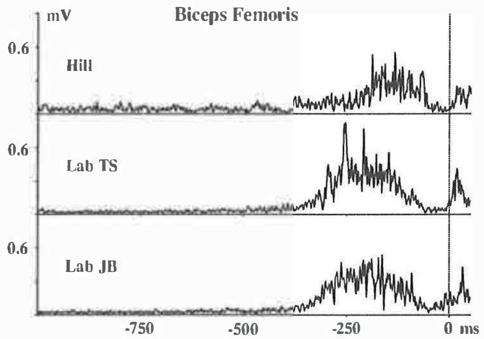


FIGURE 18 Mean (n = 4 – 6) Fz- and Fy-force, plantar pressure (heel, toe) and EMG patterns from one world champion ski jumper during take-off under real (Hill) and simulated laboratory conditions with training shoes (Lab TS) and jumping boots (Lab JB). Zero on the time scale indicates the release instant under Hill conditions and toe-off instant under Lab conditions.

TABLE 4 Kinematic take-off parameters with training shoes and jumping boots.

	Initial Position		Final Position		
	Training Shoes	Jumping Boots	Training Shoes		Jumping Boots
Ankle angle (°)	70.8	70.6	114.3	***	91.1
Knee angle (°)	71.8	70.7	167.6	***	155.2
Hip angle (°)	25.4	27.2	144.4	**	138.6
Trunk (°)	6.7	9.8	40.9		40.4
Shank (°)	53.1	53.2	64.5	**	57.1

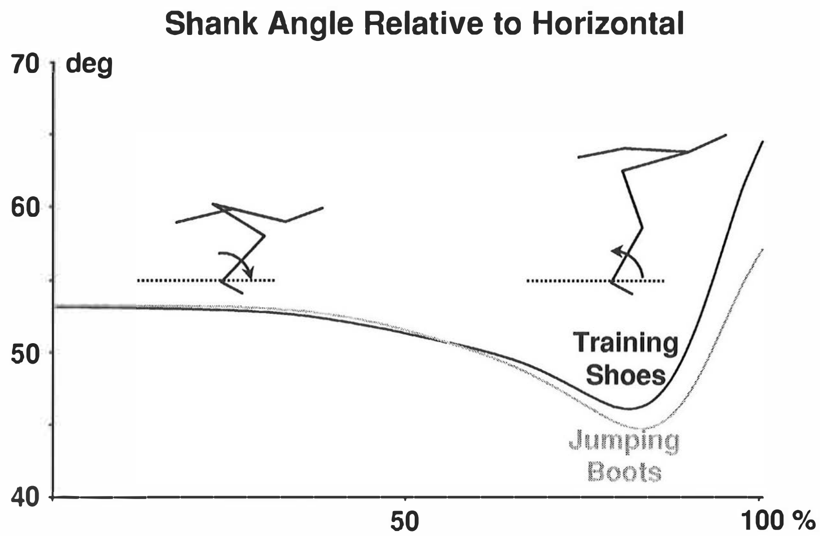


FIGURE 19 Time-normalised mean shank angle (n = 10) during take-off, with training shoes and with ski jumping boots.

5.3 Wind tunnel experiments

The means of all the take-off variables for all three jumpers in three different wind conditions and the corresponding values of the second wind tunnel experiment are presented in table 5. The wind conditions resulted in a significant decrease in take-off time in all jumpers. The decrease was 11.3, 13.9 and 14.4 % for jumpers JA, JS and ML, respectively, at the highest wind speed (fig. 20) and 14.1 % for the group of 12 jumpers. Figure 21 shows an example of the vertical force curves in non-wind and wind conditions. A vertically directed take-off (labelled as a vertical jump in figure 21) emphasised the short take-off time found in wind conditions. Strong consistence of jumpers' several consecutive trials in both conditions is demonstrated in figure 22. The decrease in take-off

TABLE 5 Means (± SD) of all take-off variables for three jumpers (JS, JA and ML) in three different wind conditions (variables for the group of 12 jumpers are mean values from three different wind conditions: 21, 25 and 29 m*s^{-1} consisting of 144 trials together).

	Wind (m*s^{-1})	Take-off time (ms)	Max Force (N)	Average Force (N)	Inrun position Drag (N)	Inrun position Lift (N)	"Flight" Lift/Drag (N)
JS	0	410 ± 27	747 ± 20	443 ± 39			
	27	374 ± 17 [a]	731 ± 30	446 ± 37	59.7 ± 6.3	50.4 ± 3.2	
	33	353 ± 11 [b]	722 ± 30	448 ± 41	81.4 ± 4.1	70.3 ± 1.5	
JA	0	457 ± 13	852 ± 27	423 ± 16			
	27	422 ± 7 [c]	816 ± 44	432 ± 16	39.2 ± 6.9	22.3 ± 0.8	236/216
	33	405 ± 15 [c]	740 ± 67 [a]	416 ± 28	72.8 ± 10.9	18.8 ± 3.1	
ML	0	298 ± 21	718 ± 18	382 ± 28			
	27	264 ± 37 [a]	741 ± 40	381 ± 47	42.8 ± 2.3	5.2 ± 2.2	222/188
	30	260 ± 16 [b]	705 ± 24	347 ± 17 [a]	54.3 ± 2.0	8.2 ± 5.5	
12	0	533 ± 76	720 ±152	296 ± 72			
	21 - 29	458 ± 51 [b]	732 ± 155	341 ± 48 [b]			

Significant differences between non-wind and wind condition are shown by the following indexes: (a) $p < 0.05$, (b) $p < 0.01$ and (c) $p < 0.001$.

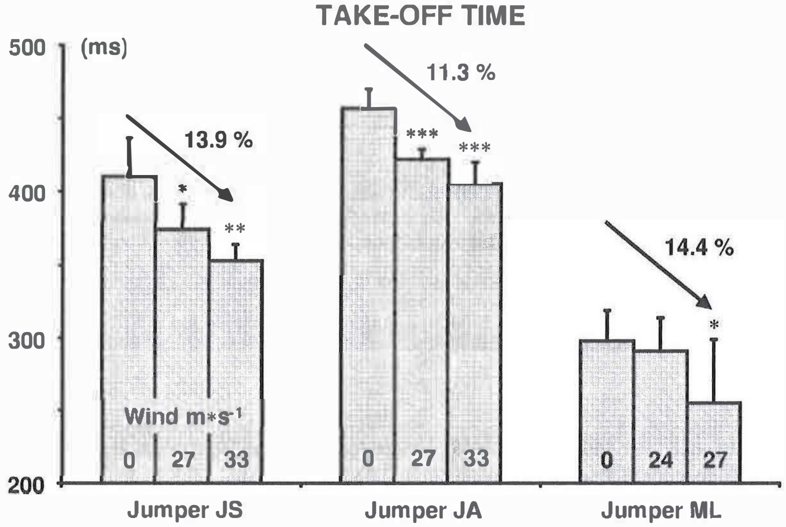


FIGURE 20 Take-off time of three different jumpers in three different wind conditions.

time of jumper JA was significant with the Datalogger as well (457 ± 13 ms, 432 ± 9 ms in non-wind and wind condition respectively). The peak take-off forces were not affected by the wind (table 5), except for subject JA at the two highest wind speeds. The average lift force during the take-off in wind speed of 27 m*s^{-1} was 72 N and 100 N for jumpers JA and JS, respectively. EMG activities did not show any major differences between the non-wind and wind conditions as demonstrated by the time-normalised presentation in figure 23. Columns titled "inrun position" in table 5 show the aerodynamic forces of the jumpers' initial take-off position. Jumper JS showed much higher drag (59.7 ± 6.3 N, wind speed 27 $m*s^{-1}$) and lift values (50.4 ± 3.2 N) than jumpers JA and ML (39.2 ± 6.9 N, 22.3 ± 0.8 N and 42.8 ± 2.3 N, 5.2 ± 2.2 N, respectively) at every wind speed. These aerodynamic forces were also strongly interrelated for jumper JS (r = 0.942, p < .001). Figure 24 shows a comparison of the upper body angle from the horizontal between jumpers JA and JS.

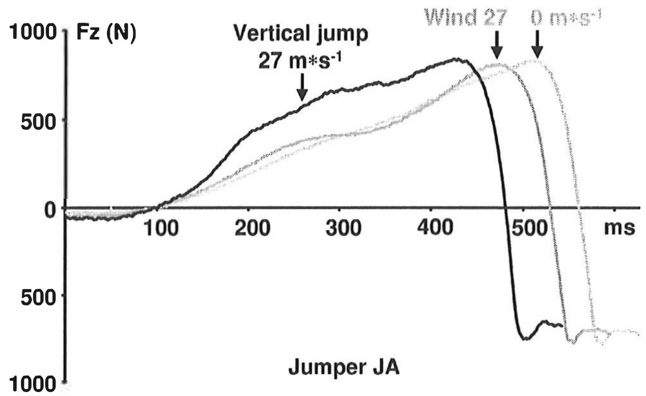


FIGURE 21 Vertical take-off force curve of one jumper in different wind conditions. In the vertical jump, take-off was directed straight upward. The zero force level is set to the jumper's body weight.

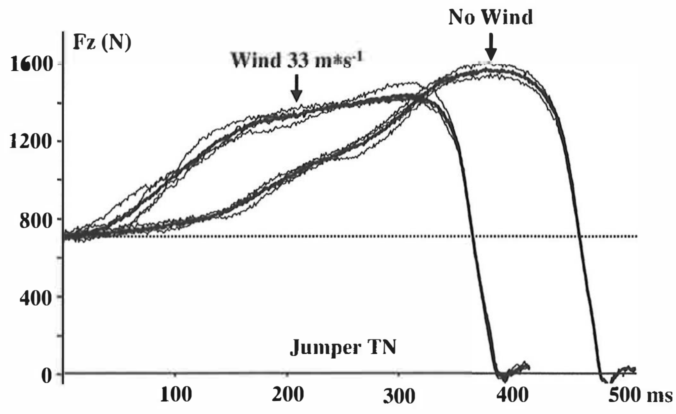


FIGURE 22 Mean vertical take-off force curves (including five originals) from one jumper in non-wind and wind conditions.

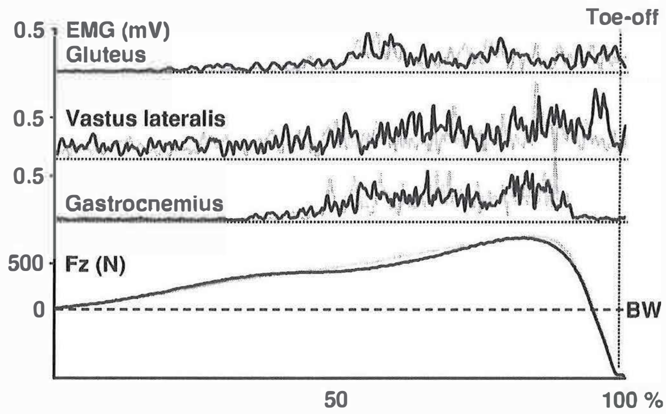


FIGURE 23 Time-normalised EMG patterns of one jumper in non-wind and wind (bold) conditions of 27 m*s^{-1}.

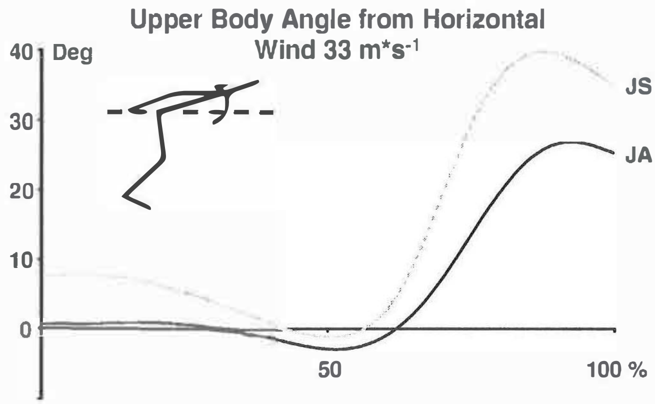


FIGURE 24 Comparison of the upper body angle from horizontal between jumpers JS and JA in wind condition of 33 m*s^{-1}.

The vertical take-off velocity derived from the net impulse in the non-wind condition (JA 2.68 m*s^{-1}, JS 2.63 m*s^{-1} and ML 1.97 m*s^{-1}) decreased significantly for all jumpers (JA 2.34 m*s^{-1}, JS 2.29 m*s^{-1} and ML 1.72 m*s^{-1}, $p < 0.001$) at the highest wind speed. The same vertical take-off velocity calculated for the body's centre of mass from the video analysis did not change with wind speed (fig. 25).

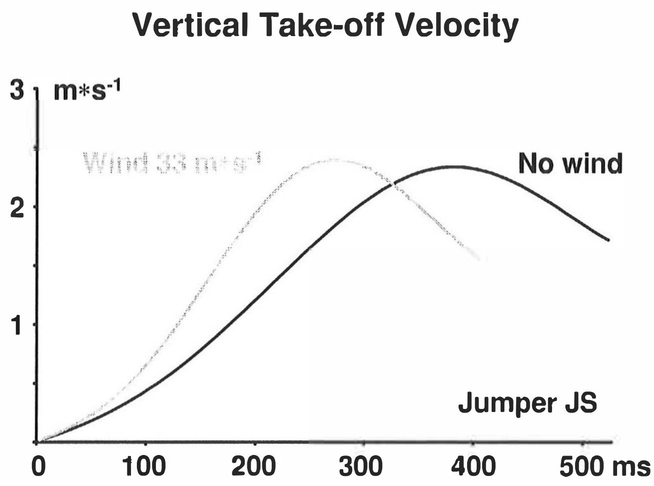


FIGURE 25 Vertical take-off velocity of the body's centre of mass for jumper JS in non-wind and wind conditions.

Comparison with computer simulation

The parameters of jumper JA were fed into the simulator as a reference. The official inrun velocity (photocell) was set to 92 km/h (25.6 $m*s^{-1}$) by adjusting the starting gate. The flight aerodynamics was adjusted to give a reference jump of 120 m. The simulation results are presented in table 6. In all cases the flight aerodynamics was kept the same. JS 1 had the same measured take-off force as jumper JA. If, however, the vertical take-off velocity for jumper JS is calculated from his own measured take-off force (case JS2 in table 6) the final length of his jump is further reduced.

TABLE 6 Comparison of two jumpers JA and JS with typical parameters in Lahti K – 114-m hill profile.

	Cd inrun	Cl inrun	$Vv_{take-off}$ ($m*s^{-1}$)	$V_{official}$ ($m*s^{-1}$)	Jump length (m)
JA	0.082	0.028	2.55	25.6	120
JS1	0.136	0.117	2.55	25.1	100.9
JS2	0.136	0.117	2.35	25.1	93.7

6 DISCUSSION

6.1 The feasibility of the Paromed Datalogger® in ski jumping

According to the subjective feeling of the jumpers the equipment used in this study did not disturb their performance, even though in some cases the jumpers felt that the airstream on the back of the body was abnormal during the flight phase. One reason for this could be that the limited space for the datalogger under the jumping suit creates a 'hunchback' shape which possibly leads to a separation of the airstream. Separation occurs on the upper side of an airfoil if its angle of attack exceeds a critical value. When this happens, the airfoil loses much of its lift, and stalls (Alfredsson et al. 1988). However, the results of the wind tunnel experiments did not show any evidence for a possible effect of the datalogger on aerodynamics during take-off (see 6.4).

On the basis of the comparison between the calculated relative centrifugal force and the measured plantar pressure on the inrun curve (fig. 10), the Paromed system seems to be sensitive to the changes of pressure that occur during ski jumping. The relative pressure values matching the calculated relative centrifugal force were recorded from the very beginning of the inrun curve; at this phase the jumpers' position was assumed to be fairly static, involving neither effects of take-off action nor any change in the inrun curve gradient. The large variability between the trials may be due to overcompensation for the sudden extra loading occurring in this phase (see fig. 7, sensor # 16). The take-off action starts before the jumper reaches the end of the inrun curve, which would explain the difference between the calculated and measured pressure increase during the curve.

The highest pressures among all the sensors during take-off were measured under the medial side of the fore foot; this implies that while the jumper's centre of mass moves forward the take-off action has a strong lateral component from both feet. However, large interindividual differences were observed, as demonstrated in the examples in figure 11. An asymmetric pressure distribution between the right and left foot can be seen in the case of ML (fig. 6). Despite this jumper's unbalanced force production between the legs, this particular jump can be considered good as performed with a fairly low speed (82 m, 22.4 $m*s^{-1}$). In case of jumper APN, because the take-off has a strong increase in big toe pressure, the inrun posture (Fig. 6 and 11) with the weight slightly on the forepart of the feet is probably favourable for a balanced take-off. In order to obtain a proper flight position jumpers have to move their upper body forward during take-off (Virmavirta and Komi 1993a). This means that if there is too much weight on the heels before take-off, the jumper may have to produce excessive forward rotation during the take-off, as can be seen in the case of jumper KS, who displays a sudden pressure increase under the toes during take-off (Fig. 11). The interindividual differences observed in the increase in pressure may reflect an unstable anteroposterior balance while the jumper tries to create the correct forward rotation for a good flight position. Jumper APN (Fig. 6 and 11) shows that a balanced increase in anteroposterior pressure under the feet during take-off is an important prerequisite for a good performance (93 m, 23.2 $m*s^{-1}$) in ski jumping. Good jumpers also display minimal across-jump variability in the pressure distribution under their feet during take-off, as can be seen from the deviation bars in figure 11.

6.2 Hills of different sizes

The results of this study showed that the differences in plantar pressure and muscle activation patterns between the three differently-sized hills were smaller than expected for both jumpers. A good explanation for the similarity between the data collected from the different hills can be found from the information on hill construction (table 2). Different profiles guaranteed that the centrifugal force ($mv^2 * R^{-1}$) was almost the same for each hill (approx. 60 % of the jumpers' bodyweight). Furthermore, the jumpers stayed for a fairly equal time (approx. 250 ms) on the flat portion of the take-off ramp where the take-off action mainly takes place. It seems that in regard to the parameters mentioned above, the hills used in this study provided equal conditions for take-off.

In figure 12 the bars represent the mean values for all the trials performed by two jumpers on three different hills; and they thus give an overall view of the ways in which pressure changes on different areas of the foot sole. A small variability undoubtedly indicates small differences between the hills. It was also interesting that on all three hills there was a strong shift of pressure to the medial side of the fore foot during the final take-off phase. In our recent studies on plantar pressure distribution this medial side loading has been found to be natural, both in simulated and in real ski jumping take-off.

The equal maximum pressure values found on differently-sized hills (fig. 14) indicate that take-off was probably performed with the same effort in all the conditions measured. On the basis of their contribution to the take-off action (fig. 13, phases 3-5) the VL and GL muscles can be considered to be the main take-off muscles. The small changes in EMG amplitudes between the hills (fig. 15a and b) support the assumption that take-off was performed with the same intensity on different hills. The timing of the GL EMG demonstrates the similarities in muscle activation on the three different hills. The firing of the GL and VL (fig. 15a) muscles more than 250 ms before the take-off edge supports an earlier finding that the take-off action is started already on the inrun curve (Schwameder 1993, Virmavirta and Komi 1993).

Some of the phases analysed showed slightly higher pressure and EMG values for the small hill as compared with the larger ones (fig. 16). This is supported by the coefficients of variability (CV%), which display the smallest values between the two larger hills. The most distinct difference in pressure between the hills could be found in the shape of the pressure curve for the small hill. The higher rate of pressure production on the small hill as compared with the larger hills could be explained either by the easier initiation of take-off with high effort from a lower speed, or simply by the rapid movement of the load to the fore foot. The first assumption is supported by the countermovement type of pressure curve for the small hill. During the countermovement, the load probably moves to the fore foot and activates the plantar flexors, as seen in the GA about 250 ms before the take-off edge in figure 15b. The role of the GA and TA muscles during the inrun curve and early take-off is mostly that of balancing, and thus their behaviour may easily change even between trials on the same hill. However, the TA is activated in the same way at the end of the take-off on different hills (figure 15b) and it is quite obvious that this strong dorsiflexion when the skis are lifted limits an effective final push-off with plantar flexors.

It can be concluded that if the timing of the take-off action does not change when moving from a small hill to a large one, the take-off should be started earlier on large hills, not with respect to time but to distance. The length of the take-off table and the radius of the inrun curve in relation to inrun speed can be considered as the conditions necessary for the present results. However, since these conditions will be fulfilled in almost every design of jumping hill, it seems that ski jumping training on small hills is unlikely to disturb the movement patterns needed for larger hills, and that such training can also be helpful for special low-speed take-off training.

6.3 Simulated vs. real take-off

The most significant differences in plantar pressures and EMG activities between Hill and Lab conditions were found in the initial take-off position, when the actual Hill values were taken from the inrun curve phase. During this phase the extra load caused by the centrifugal force must be compensated for by additional muscular work. This compensation is demonstrated by the VL activation in figures 17 (inrun) and 18. The behaviour of the TA and GA activities before take-off is also different between the two conditions. In the Hill conditions both muscles work strongly to maintain a proper, anteroposteriorly well-balanced inrun position. In the Lab conditions a high activation of the TA (fig. 18) begins approximately 750 ms before take-off as the jumper rotates his body forward in order to obtain a correct take-off direction. High pressure under the medial side of the ball of the foot in Lab take-off (fig. 17) can be regarded as a result of the preceding forward rotation; by contrast, in the Hill take-off any possible forward rotation seems to result in high big toe pressure in the early phases of take-off. This difference in pressure distribution of the fore foot area between the conditions is probably caused by slightly different surface conditions. In the laboratory the surface under the footwear is flat, whereas in the hill condition the jumping boots with their stiff shoe sole rest on ski binding in the fore part and on heel blocks in the rear part; thus, the pressures are high in both of these areas.

High pressure under the big toe seems to characterise the beginning of take-off in actual jumping hill conditions (Fig. 17). However, such a degree of pressure under the fore foot is probably caused by a strong forward rotation and cannot therefore be regarded as characteristic of a good, well-balanced take-off. This assumption is supported by the pressure data from one excellent jumper (Fig. 18) with whom pressure under the big toe does not increase until the very end of the take-off. A strong shift of pressure to the fore foot at early take-off is usually associated with a yielding of the ankle angle (the shank moves forward) leading eventually to an opposite reaction (the shank moves backwards, see Fig. 19), and the remaining take-off force production is then no longer directed against the support surface. This may result in a considerable loss of height in the flight path, and also a loss in the forward angular momentum which enables a jumper to prepare for and subsequently obtain his flight position as rapidly as possible from take-off (Arndt et al. 1995).

The weak utilisation of the GA muscle during the real take-off is demonstrated in the average group results (fig. 17) as well as in the individual EMG data (fig. 18). The strong dorsiflexion needed to bring the skis to their correct flight position, plus the stiffness of the jumping boots, tend to impede the effective use of the plantar flexors that is possible in a simulated take-off with training shoes (Virmavirta & Komi 1991; Schwameder et al. 1997). This was also demonstrated by the higher pressure ($p < 0.001$) under the heel at the end of the hill take-off (last 100 ms). It is known that the plantar flexors play an important role in vertical jumps and thus also in simulated ski jumping take-offs with training shoes. However, utilisation of the plantar flexors requires strong the support on the ball of the foot, as can be seen also in the plantar pressures in the simulated take-off shown in figure 17 (last two phases of take-off). The different friction conditions in the Lab take-off make it possible to direct the take-off more forward and also maintain a more balanced support on the fore foot than is possible in actual Hill conditions with their low friction coefficient of approximately 0.05. Thus, in actual Hill conditions, where the skis and jumping boots probably do not allow pressure to remain on the ball of the foot as in Lab conditions, jumpers should try to keep the shift of pressure from heel to fore foot to a minimum. One important lesson to be drawn from this pressure shift is that simulated take-offs should be carefully controlled to take this aspect into consideration.

Due to the limited possibilities for utilising the plantar flexors in ski jumping take-off, a strong and well-coordinated function of the knee (VL) and hip (GL) extensor muscles is required for accelerated movement towards the end of take-off. The VL and GL did not show any major differences between the measured conditions, but the slightly higher activation of the VL at the beginning of take-off (fig. 17 and 18) and of the GL at the end of take-off demonstrates the existence of this co-ordination. The effective use of the upper body at the end of take-off, with minimal air resistance, has been discussed by Virmavirta & Komi (1993a). The timing of VL activation in figure 18 shows that take-off time is much longer in a simulated take-off, even though the release instant in Hill conditions does not precisely match the toe-off instant in the Lab with regard to knee angle. The activation time of the VL on the Hill supports the view (Virmavirta & Komi 1993a) that take-off is already begun on the inrun curve, before the flat take-off table (6 m).

6.3.1 The effect of jumping boots on take-off

With respect to initial take-off position (inrun), as represented by the angle at the ankle, knee and hip joint as well as by the EMG activities and plantar pressures, no significant differences appear between the conditions with different footwear; thus, the conditions necessary for a comparison are fulfilled. However, the final take-off positions showed large differences, which were most apparent in the movement of the ankle, joint. The weaker plantar flexion with jumping boots (91.1 vs. 114.3º) resulted in a less extended knee and hip joint at the release instant (table 4) thus also preventing the shank from moving backwards (fig. 19). This weak utilisation of the plantar flexors is most probably caused by the stiff structure of ski jumping boots (Virmavirta and Komi 1991). It has been shown that in a push-off without plantar flexion, as is the case in speed skating (with conventional skates), one is not able to fully extend the knee during push-off (Ingen Schenau et al. 1987). Maintenance of the proper shank angle throughout take-off has been found to be one of the most important prerequisites for effective force production (Virmavirta and Komi 1994, fig. 26). In the present study, the strong forward rotation of the shank preceding the subsequent backward movement can be seen in figure 19.

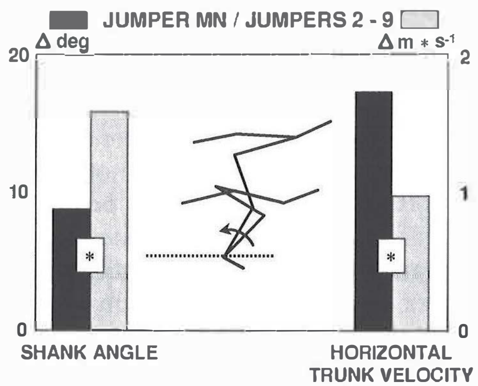


FIGURE 26 Comparison of shank angle displacement and change in horizontal trunk velocity during take-off between the jumper MN and jumpers placed 2 – 9 in one competition (Virmavirta 1999).

In table 3 it can be seen that at least part of the differences found in the velocity parameters with different footwear can be accounted for by the differences in footwear mass. The similar Fy impulse in both footwear cases shows that because the change in momentum during take-off equals the Fy impulse (see equation 3) the difference in horizontal take-off velocity can be simply explained by the heavier ski jumping boots. However, the difference in the Fz impulse shows that the different mass of the footwear used does not explain all of the difference between the conditions. If the mass of the jumping boots was set at that of training shoes there would still be significant difference in vertical and resultant velocity between the conditions (vertical velocities 2.38 vs. 2.25 $m*s^{-1}$, $p < 0.01$; resultant velocities 2.78 vs. 2.67 $m*s^{-1}$, $p < 0.01$). Vaverka et al. (1993) examined the difference between the support phase (in which a jumper mainly accelerates the masses of his body, suit and helmet) and the non-support phase (after release, when the final velocity of the system "jumper-skis" is relative to the total mass of jumper and equipment). Neglecting the mass of the equipment they calculated the theoretical velocity from force impulse and designated it as a factual level of utilisation of take-off ability during take-off in jumping hill conditions. The same principle could also be applied in this study, as the mass of the jumping boots does not move until the very end of the take-off. With jumping boots the jumpers reached 91.6 % of the vertical take-off velocity and 93.2 % of the resultant take-off velocity achieved with training shoes and the calculated factual levels of utilisation of take-off abilities were 94.5 and 96.0 %, respectively.

The differences in final take-off positions are supported by the EMG data from which the most significant differences were found in the action of gastrocnemius and gluteus muscles (fig. 17). The limited plantar flexion with the jumping boots is also demonstrated in figure 18 in which the average GA EMG patterns of one jumper are shown. This comparison between training shoes and jumping boots gives results very similar to those in the study of Schwameder et al. (1997) where the duration (264 ms for the TS and 230 ms for the JB) and amplitudes of gastrocnemius activation were analysed. The high activation of the tibialis anterior (fig. 18) beginning approximately 750 ms before take-off as a jumper rotates his body forward in order to obtain a correct take-off direction is consistent with the forward rotation of the shank in figure 20. This early rotation is emphasised in the take-off with training shoes, as demonstrated by the difference in pressure under heel and ball in figure 17 (300 – 200 ms) as well as by the TA activation in figure 18. A higher pressure under the heel area was maintained longer with jumping boots. The thicker sole under the heel of jumping boots help jumpers and - especially those jumpers who have a stiff ankle joint structure - to keep an anteroposteriorly more balanced position during take-off. Figure 17 (300 - 200 ms) demonstrates this typical phenomenon of jumpers with a stiff ankle joint, as the ball area shows high pressure and the heel area low pressure with training shoes. Figure 17 also shows that the sensors on the medial side of the ball area are more loaded than the corresponding lateral sensors during the latter parts of the take-off (200 – 100 ms and 100 – 0 ms); this would seem to be a natural feature in vertical jumps of this kind.

High pressure under the fore foot (ball and toe) with jumping boots characterise the final phase of take-off in this study. However, such a high pressure is probably caused by too strong a forward rotation and it cannot therefore be regarded as characteristic of a good, well-balanced take-off. The difference between training shoes and jumping boots in this phase is significant ($p < 0.001$) and is likely to depend on the different structure of the footwear. The more flexible sole of the training shoes obviously allows jumpers to maintain a balanced position when the load is on the ball, whereas too much pressure may easily shift to the toes while using jumping boots with a stiff sole.

The results of this study showed differences in simulated ski jumping take-off with training shoes and jumping boots. The differences in take-off velocities (representing the final output of take-off) can be mostly accounted for by the different utilisation of plantar flexion. A shorter range of plantar flexion with ski jumping boots together with an equal effort of the knee extensor muscles and somewhat lower hip extensor activation results in significantly lower vertical and resultant take-off velocities. Therefore, for effective take-off with jumping boots the role of the knee extensor and possibly hip extensor muscles should be emphasised. On the basis of the measured pressure distributions it can be concluded that the stiff structure of jumping boots may result in a shift of pressure too much forward thus limiting the effective vertical force production. One important consequence of such a pressure shift is that the movement pattern of simulated take-offs is carefully controlled, especially when using training shoes. Nevertheless, although these results are very relevant to practical ski jumping performance, they do not allow any clear answers as to how ski jumping boots should be modified to allow the best possible take-off performance without compromising various other important prerequisites such as the stability of the boot.

6.4 Ski jumping take-off in wind tunnel

The significant decrease found in the take-off time of all jumpers in the various wind conditions is the main finding of the present wind tunnel study. Because it is known that aerodynamic lift is close to zero in a good initial take-off position and is over 300 N in the flight position (see also table 5), the lift force during take-off is expected to be somewhere between these two values. Therefore the short take-off time in wind conditions can be regarded as resulting from a reduced load under the influence of aerodynamic lift. This means that in non-wind condition the load, that jumpers are working against, is their own bodyweight (mg) while in wind condition this load is reduced by the aerodynamic lift force (mg – L).

The maximum and average net forces did not change much with the increased wind speed and thus a lower vertical take-off velocity was expected in wind conditions with a decreased force production time. The minor decrease in the maximum force of jumper JA could be interpreted as the limited capacity of the muscles to produce force under a high contraction velocity. Since the jumpers' vertical take-off velocity was roughly the same in the non-wind and wind conditions as demonstrated in the comparison in figure 25, it is quite obvious that the aerodynamic lift force assists take-off by reducing load. In the second wind tunnel experiment with 12 jumpers the average take-off force increased in wind conditions. This can be explained by much higher rate of force production in wind condition (fig. 22). The effect of wind was emphasised in this experiment probably because of jumpers' limited take-off capacity in non-wind condition at such an early phase of training season.

The behaviour of aerodynamic lift during take-off remains masked when analysis focuses on the ground reaction forces, which include both take-off forces and aerodynamic forces. However, it is possible to solve the average lift force during take-off by using equations for average acceleration and thereafter for average force. The difference in average force between the conditions gave the average aerodynamic lift force of 72 N and 100 N for jumpers JA and JS, respectively. These values are in good agreement with the lift forces in table 5. In the schematic illustration presented in figure 27 the one possible behaviour of aerodynamic lift is outlined by the shaded area under the initial bodyweight just before take-off. In wind conditions the shaded area compensates for the loss in impulse caused by the shorter take-off time with the same take-off force. The true progression of the lift force is not necessarily this evident towards the end of take-off phase. The decrease in take-off time was further emphasised in the vertically directed take-off as the take-off force was exerted in the same direction as the aerodynamic lift force. It is probable this kind of force production closely resembles take-off in field condition, where, owing to the low friction between skis and track ($\mu = 0.05$, Ward-Smith and Clements 1982) all the force is exerted perpendicularly against the take-off table. However, from the jumpers' point of view the vertically directed take-off may be experienced strange as they move backwards with the wind after the ground contact.

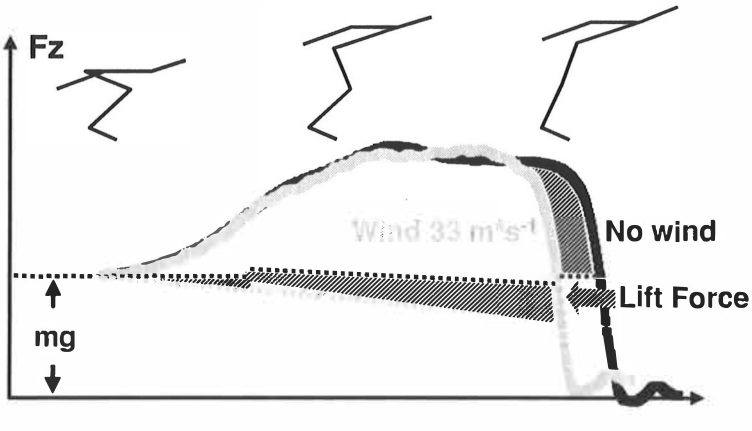


FIGURE 27 Schematic illustration of the possible behaviour of aerodynamic lift during ski jumping take-off.

It is perhaps not only a coincidence that the differences in force curves of figure 28 between non-wind and wind conditions have similar features with the force curves of vertical jumps from subjects having different fast twitch muscle fibre composition in their vastus lateralis muscle.

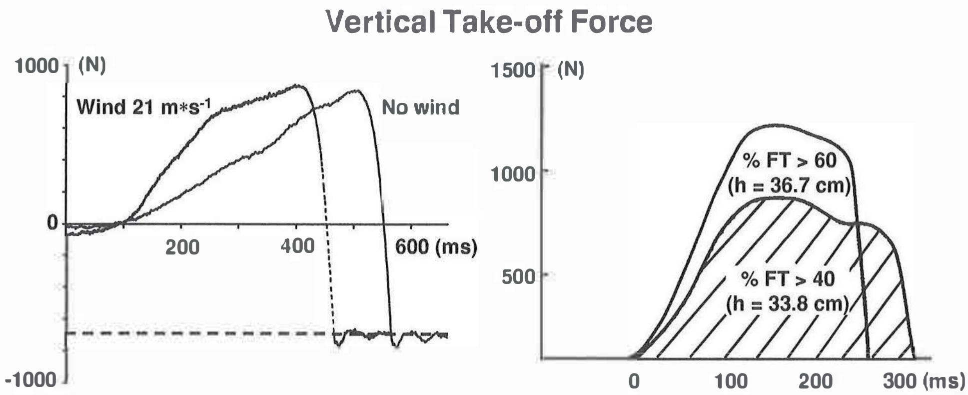


FIGURE 28 Left: Vertical force curves of simulated take-off from one jumper in non-wind and wind conditions as measured in the wind tunnel.
Right: Corresponding force curves of vertical jump from subjects having different fast (FT) muscle fibre composition in their vastus lateralis muscle (Bosco and Komi 1979).

The aerodynamic quality of the jumpers' initial take-off position is shown in table 5. The high air resistance of jumper JS at every wind speed certainly prevents him from achieving a high final inrun speed, which is the most important factor affecting jumping distance (Virmavirta and Komi 1993b). High air resistance creates also an unfavourably large lift force before the take-off as can be seen in table 5. This lift is generated when the air goes under the upper body in an unfavourable inrun position (fig. 24). The jumpers' different abilities to utilise aerodynamic lift during take-off are probably caused by the behaviour of the air stream around the upper body before and during take-off. Jumper JS had a large upper body angle relative to the horizontal, which means that a greater frontal surface area was exposed to air resistance. A good lift-assisted take-off helps the jumper to obtain a proper flight position (forward leaning) right after take-off.

The limited computer simulation used in the present study revealed interesting features. The difference of 1.5 km $*$ h^{-1} in the measured velocity (photocells) and almost 20 meters in jump length between JA and JS1 is mostly determined by the higher Cd value of JS during the inrun position. Furthermore the 1 % change in Cd of the reference JA results in a 0.03 % change in photocell velocity and a 0.17 % change in jump length. More significantly, a 1 % change in photocell velocity results in a change of 5.7 % in jump length.

6.5 Perspective

The results of this study clearly showed that a well balanced initial take-off position is an absolute prerequisite for a good take-off in ski jumping. Following on from this, a new force plate arrangement which gives separate Fz-force components from the rear and fore part of the plate was tested in a wind tunnel. The preliminary results of this experiment show that an excellent jumper with a balanced initial take-off position is also able to keep his anteroposterior force balance much longer and produce higher forces than a less skilful jumper (fig. 29). Projects are in progress to utilise the new force plate arrangement in order to characterise the factors involved in a balanced take-off in simulated non-wind and wind conditions.

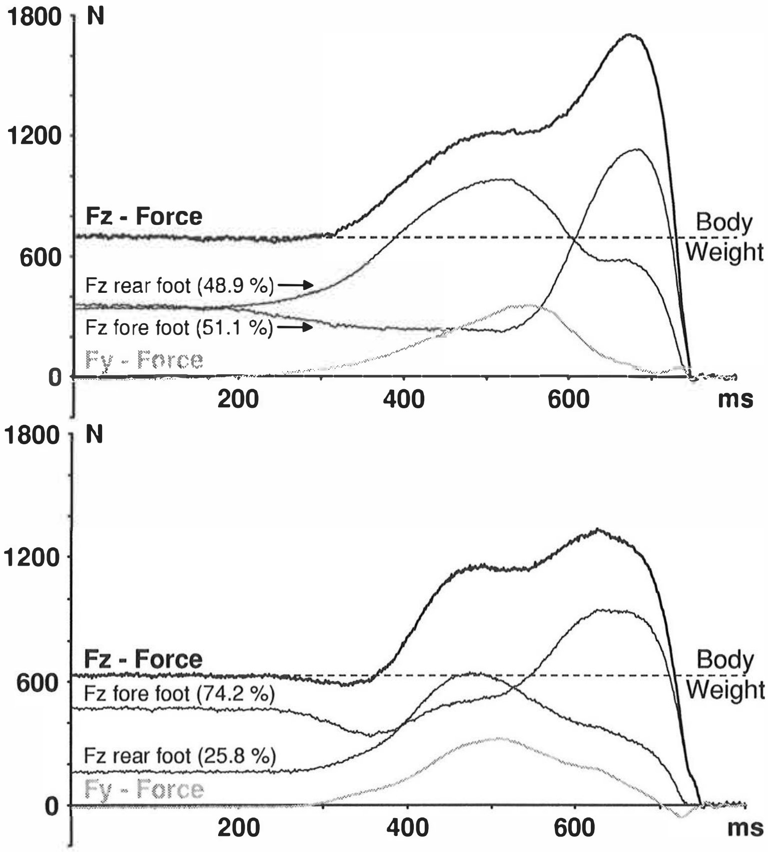


FIGURE 29 Vertical (Fz) and horizontal (Fy) take-off forces with vertical fore and rear foot components from one excellent ski jumper (above) and one less skilful jumper (below) in simulated non-wind conditions. The different force distributions of the two jumpers can be observed in the initial take-off position and throughout the entire take-off.

7 PRIMARY FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarised as follows:

(1) The test procedure for the Datalogger used in the present study showed that this system could be used in ski jumping with only minor disturbance to the jumper. The wind tunnel experiments did not show any special effect of datalogger on aerodynamics during take-off. The good fit between the measured relative pressure increase and the calculated relative centrifugal force during the inrun curve served as a rough indication of the validity of the system. The anteroposterior balance of a jumper could be examined with the Datalogger system.

(2) The results of this study showed that differences in plantar pressure and EMGs between differently-sized jumping hills were smaller than expected. The results suggests that ski jumping training on small hills does not disturb the movement patterns for bigger hills and that it could also be helpful for special take-off training at low speed.

(3) The simulated and real ski jumping take-offs differ significantly in plantar pressure and muscle activation patterns. The most significant differences were found in muscle activation and plantar pressures prior to take-off. The centrifugal force due to the curvature of the inrun in real jumping hill conditions caused extra pressure under the fore and rear parts of the feet and therefore higher activation in all muscles. For the jumper, adequate sensory perception of this extra pressure and its release while entering the take-off table is obviously very important in regard to correct timing of the take-off. There were also significant differences between the conditions in the utilisation of the gastrocnemius, with its relation to anteroposterior pressure under the feet. It seems that for effective force production during take-off the pressure under the fore and rear foot should be kept balanced for as long as possible, resulting in an important role for the knee and hip extensor muscles.

(4) The aerodynamic lift caused by the wind in the wind tunnel brings simulated ski jumping take-off closer to field jumping conditions and helps the jumpers to perform take-off in the split second on the take-off table more effectively than has hitherto been believed possible. Reducing the take-off time, with a higher rate of force production and minor changes in the EMG, would produce a more explosive take-off. Moreover, the proper utilisation of aerodynamic lift during take-off might help the jumper to maintain the aerodynamic inrun position longer, which would also guarantee a high final inrun speed.

YHTEENVETO

Mäkihypyssä lopputulokseen vaikuttaa ratkaisevasti hypyn pituus. Hypyn eri vaiheet – vauhti, ponnistus, ilmalento ja alastulo valmistautumisineen – vaikuttavat kaikki hypyn pituuteen. Ponnistusta pidetään koko suorituksen tärkeimpänä vaiheena, koska se määrää lentoonlähtönopeuden, ponnistuskulman, kiertomomentin ja hyppääjän asennon lennon aikana. Keskustelu mäkihypyn ponnistuksen merkityksestä on seurannut ilmalentovaiheen aerodynamiikassa tapahtunutta kehitystä (esim. hyppypuvut, lentotyyli). Usein tämä kehitys aerodynamiikassa (V-tyyli, Mahnke & Hochmuth 1990) on lisännyt hyppyjen pituuksia niin paljon, että valikoitujen ponnistusmuuttujien tarkkaa vaikutusta suoritukseen on ollut vaikea arvioida. Koska lennon aikaisten aerodynaamisten nosto- ja vastusvoimien merkitys on mäkihypyssä todella suuri, tulisi kattavan ponnistusanalyysin sisältää myös nämä tekijät.

Mäkihypyn ponnistus tapahtuu melko äärimmäisissä ja muuttuvissa olosuhteissa. Suuren nopeuden aikaansaama lyhyt ponnistusaika sekä vauhtimäen kaarteen aiheuttama paine asettavat erityisiä vaatimuksia hyppääjien hermolihasjärjestelmälle. **Tämän tutkimuksen tarkoituksena oli selvittää mitkä tekijät mahdollisesti rajoittavat tehokasta ponnistusta mäkihypyssä. Erityisesti haluttiin tutkia mäkihyppääjien hermolihasjärjestelmän toimintaa simuloiduissa laboratorio- ja tuulitunneliolosuhteissa.**

Yksi hyvän ponnistuksen tärkeimmistä edellytyksistä on tasapainoinen asento, jota selvitettiin Paromed Datalogger® paineanturijärjestelmällä useissa tähän tutkimukseen liittyvissä mittauksissa. Järjestelmä osoittautui käyttökelpoiseksi mäkihypyssä aiheuttaen vain vähäistä häiriötä hyppääjille. Tuulitunnelikokeiden perusteella hyppääjän selässään puvun alla kantama datalogger ei myöskään vaikuttanut ponnistuksen aikaiseen aerodynamiikkaan häiritsevästi. Laitteen mittaama suhteellinen paineen kasvu vauhtimäen kaarteella vastasi hyvin laskettua suhteellista keskipakovoimaa, mikä antoi karkean arvion järjestelmän validiteetista. Erityisesti hyppääjän tasapaino eteen-taakse-suunnassa kyettiin hyvin mittaamaan laitteella.

Hyppääjien jalkapohjan alta mitattujen paineiden sekä ponnistukseen osallistuvien lihasten käyttäytyminen eri kokoisissa mäissä poikkesi odotettua vähemmän. Näin ollen mäkihyppyharjoittelu pienissä mäissä tuskin sekoittaa isommissa mäissä tarvittavia liikemalleja vaan päinvastoin se voi jopa toimia ponnistuksen erikoisharjoitteluna hitaalla nopeudella.

Simuloitujen ja todellisissa olosuhteissa suoritettujen ponnistusten välinen vertailu osoitti, että paineen jakautuminen jalkapohjan alla ja lihasten aktivaatiomallit poikkesivat molemmat merkittävästi toisistaan. Suurimmat erot ilmenivät ennen ponnistusta vauhtimäen kaarteen aikaansaaman keskipakovoiman aiheuttamana lisääntyneenä paineena ja lihasten aktiivisuutena. Vauhtimäen kaarteella lisääntyvän paineen ja sen katoamisen hyppyripöydällä aistiminen sekä ponnistuksen aloittaminen tämän paineen alla ovatkin todennäköisesti edellytyksenä ponnistuksen onnistuneelle ajoitukselle. Erittäin merkittävä ero mitattujen olosuhteiden välillä löytyi myös nilkan ojentajalihaksiston hyväksikäytössä ja siihen liittyvässä jalkapohjan eteen-taakse-suunnan painejakaumassa. Jäykkä mäkikenkä ja suksien käyttäytyminen (kiertomomentti) alkuilmalennossa eivät salli nilkan ojentamista siinä määrin kuin esimerkiksi tavallisessa vertikaalihypyssä (vrt. myös pikaluistelun potku perinteisellä luistimella). Tehokkaan voimantuoton kannalta hyppääjän tulisi säilyttää paine tasaisesti jakaantuneena jalan taka- ja etuosalle niin kauan kuin mahdollista, mikä korostaa polven ja lantion ojentajalihaksiston merkitystä mäkihypyn ponnistuksessa.

Tuulitunnelissa syntyvä aerodynaaminen nosto- ja vastusvoima saavat simuloidun mäkihyppyponnistuksen muistuttamaan enemmän todellista hyppysuoritusta. Aerodynaaminen nostovoima keventää kuormaa ja samalla auttaa hyppääjiä suorittamaan ponnistuksen lyhyemmässä ajassa kuin mitä on arveltu. Lyhentynyt ponnistusaika (n. 14 %) yhdessä suuremman voimantuottonopeuden ja vähäisten lihasaktivaatiomuutosten kanssa korostaa mäkihypyn ponnistuksen "räjähtävää" luonnetta. Aerodynaamisen nostovoiman oikea hyväksikäyttö ponnistuksessa auttaa hyppääjää myös säilyttämään laskuasennon pidempään, mikä taas takaa suuren lentoonlähtönopeuden.

Tämän tutkimuksen tulokset tärkeimmistä ponnistusta rajoittavista tekijöistä ovat jokseenkin yhteneviä tämänhetkisen yleisen mäkihypyn ponnistusta koskevan käsityksen kanssa. Voimantuoton kannalta hyppääjän on kyettävä tuottamaan riittävästi voimaa alustaa vastaan, mikä edellyttää, että hyppääjän painopiste ei liioin siirry eteen eikä taakse ponnistuksen alkuvaiheessa. Vauhdin ja vauhtimäen kaarteen aikaansaama keskipakovoima ja sen katoaminen hyppyripöydän alussa sekä aerodynaamiset voimat ponnistuksen aikana todennäköisesti aiheuttavat hyppääjille suuria vaikeuksia voimantuoton kannalta tasapainoisen ponnistusasennon säilyttämisessä.

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ORIGINAL PAPERS

I

Plantar pressure during ski jumping take-off

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II

EMG activities and plantar pressures during ski jumping take-off in three different size hills

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IV

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V

Ski jumping boots limit effective take-off in ski jumping

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