

KINEMATIC ANALYSIS OF AN INDOOR SKI JUMPING SIMULATOR

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Introduction

Since 1927, ski jumping has been analyzed using biomechanical methods based on wind tunnel experiments (Strauman, 1927). Since then, many biomechanists have studied other aspects of ski jumping using new and modern equipment made available over a period of decades (Campbell, 1990). Often, ski jumping is divided into three separate phases for biomechanical analysis. These phases are **inrun**, take-off and flight. In this study we examined the take-off phase.

The skier begins a jump at the top of the **inrun** that is a ramp supported by steel scaffolding, cement, wood or by contoured ground (Wright, 1991). A ski jumper standing on the top of the **inrun** possesses a great amount of potential energy that is changed into kinetic energy as the jumper skis down the **inrun** (Campbell, 1990).

At the base of the **inrun**, the skier must move instantaneously from the **inrun** tuck position to the flight position. The jumper then increases knee and hip angles to increase lift forces by exposing more surface area to the air (Campbell, 1990). The take-off is the most critical aspect of ski jumping because of the importance of timing and the biomechanical position of the jumper (Pulli, 1979). The goal of the skier during the take-off phase is to maximize velocity and lift (Pulli, 1979). Because of the technicality of the sport, hundreds of hours must be spent just practicing the take-off. Therefore, a need exists to develop an effective simulator where athletes can practice the timing and biomechanical aspects of the take-off year round. The United States Olympic Education Center (USOEC) at Marquette, Michigan, has assembled such a simulator constructed of wood and steel **tracking**.

This study is the first stage of a plan to determine the effectiveness of an indoor ski jumping simulator. The objective of this stage was to describe the kinematics involved during the take-off phase of an indoor simulator. The second and third stages will consist of a kinematic and kinetic comparison of simulated ski jumping to on-snow ski jumping.

Methods and Procedures

The purpose of this study was to determine the effectiveness of an indoor simulator. More specifically, this study described the kinematics involved during the take-off phase, and results were compared with previous research on actual Nordic ski jumping. Campbell (1990) defined the necessary variables to describe best the take-off phase of a ski jumper. From these variables, optimal values were determined

to enhance the performance of the jump. Considering this, our variables paralleled those of Campbell's.

Seven subjects from the U.S. Olympic Training Center's Ski Jumping and Nordic Combined Team volunteered to participate in this study. The mean age, height, weight, and U.S. ranking are presented in Table 1.

Table 1.
Subject demographics.

	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	RANKING
\bar{x}	19.4	179.0	70.2	11.1
SD	± 1.8	± 4.6	± 4.7	± 5.8

Three trials were performed by each subject. The subjects were filmed from the left side during approximately the last 6 feet of the inrun to insure a complete view of the takeoff maneuver. The shutter speed was set at 1/1000 of a second, with a film speed of 60 frames/second. Using a Graf / Bar Mark II digitizing unit by Science Accessories Corporation, 19 points of each frame were digitized. Seven of the nineteen digitized points were marked on the left side of each subject using athletic tape and permanent marker. Locations of these marks were as follows: middle of the fifth metatarsal, lateral malleolus of the fibula, lateral epicondyle of the femur, greater trochanter of the femur, greater tubercle of the humerus, lateral epicondyle of the humerus, and styloid process of the ulna. The other non-marked points digitized included the entire right side, the finger tips of the left hand, left ear, and the top of the head, assuming symmetry.

The following variables were calculated and analyzed to determine the effectiveness of an indoor simulator. These included peak take-off velocity (TOV), angle of attack (AOA), peak angular acceleration of the hip (AAH), peak angular acceleration of the knee (AAK), peak vertical acceleration of the center of gravity (VAC), shank angles to the horizontal (SHA), and horizontal displacement of the center of gravity with respect to the ankle (HDC). Angle of attack was defined as the mean angle of the trunk to the horizontal during the last three frames after contact with the simulator (Remizov, 1984).

Results and Discussion

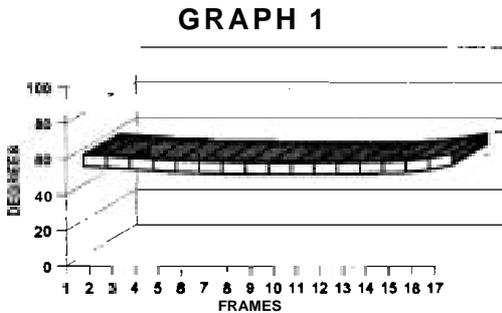
The means and standard deviations of the variables for all trials are presented in Table 2.

Table 2. Results of analyzed variables.

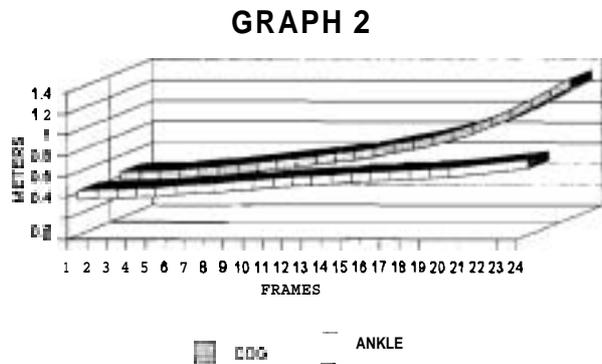
	TOV (m/s)	AOA (deg)	AAH (r/s ²)	AAK (r/s ²)	VAC (m/s ²)	SHA (deg)	HDC (Δ m)
\bar{x}	4.89	16.44	1.31	2.30	16.35	50.96	0.31
SD	± 0.18	± 11.92	± 0.62	± 0.50	± 3.02	± 4.84	± 0.07

When this data was compared with data previously published, it was found that the take-off velocity was 4.98 m/s, whereas velocities during on-snow ski jumping had been reported as high as 26.8 m/s. The angle of attack of less skilled jumpers was 17.5° which was similar to the data found in this study. Less skilled was defined by Campbell (1990) as those ski jumpers that did not place in the top 10 finishers during a pre-Olympic competition at Lake Placid. Comparative data on hip and knee angular acceleration was not available; however, it has been reported that the hip and knee contribute 25% and 65% respectively of the total change in height during take-off (Campbell, 1990). The average vertical acceleration of the center of gravity was 16.35 m/s^2 compared with 8.98 m/s^2 reported by Campbell in 1990. The

reason for the notable difference may be due to the lower take-off velocity on the simulator. Sample trials performed on the simulator are described in graphs 1 and 2. According to previous research, the shank angle in relation to the horizontal should remain constant throughout the take-off phase (Campbell, 1990). A similar



occurrence can be seen in Graph 1. In Table 2, the HDC positively increased throughout the take-off in relation to the reference point. During the take-off phase, the skier's horizontal displacement of the center of gravity with respect to the ankle should continue to increase in the direction of movement (Campbell, 1990). As seen in Graph 2, this movement does occur when a jump is performed on an indoor simulator. Displacement was calculated as the distance from the reference point.



Conclusion

It has been found that the horizontal displacement of the center of gravity with respect to the ankle positively increased in the direction of movement throughout the take-off on an indoor ski jumping simulator. The angle of attack and shank angle results also compared favorably to data obtained from on-snow ski jumping. With the exception of take-off velocity and vertical acceleration, it was concluded that this apparatus has the potential to simulate on-snow ski jumping. Although the take-off velocity was slower than on-snow ski jumping, the simulator could be beneficial for those jumpers needing practice perfecting the take-off. The slower velocity could allow the jumper to concentrate on the components of the take-off due to the

increased amount of time performing the maneuver. Therefore, it is concluded that this apparatus could be an effective year-round training device.

References

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