Biomechanical Analysis of Body Movement During Skiing Over Bumps

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INTRODUCTION

Maintenance of balance of the skier's body is one of the most important and basic techniques in skiing on slopes of various conditions. However, skiers, especially beginners are likely to lose their balance on an uneven terrain with dips and swells. In order to keep his balance during skiing on an uneven terrain, it seems to be important for a skier to avoid receiving impulse from the snow surface.

Some investigations have been conducted about maintenance of balance of body during skiing over artificially constructed bumps by means of electromyography (Miyashita and Sakurai, 1979), electrogoniometry (Iizuka and Miyashita, 1979) and cinematography (Miyashita and Sakurai, 1979, Iizuka and Miyashita, 1979, Sodeyama et al., 1979 and Ikegami et al., 1985). However, there is no research to try to measure force or acceleration acting on the skier's body during running over bumps.

Therefore the purpose of this study is to measure force acting on skier's body by analyzing the movement of skier's body mechanically as well as kinematically, and to find out essential motions to maintain the balance of skier's body against rapid change of force acting from snow surface while skiing over bumps on a straight downhill run.

METHOD

Experiment 1

Two successive bumps of the same shape were constructed artificially on a fall line of an experimental slope with 13.5 degrees inclination being 3 m away from each other. The shape of the bumps were 0.5 m in height, 2 m in length and 1.2 m in width (Fig. 1).

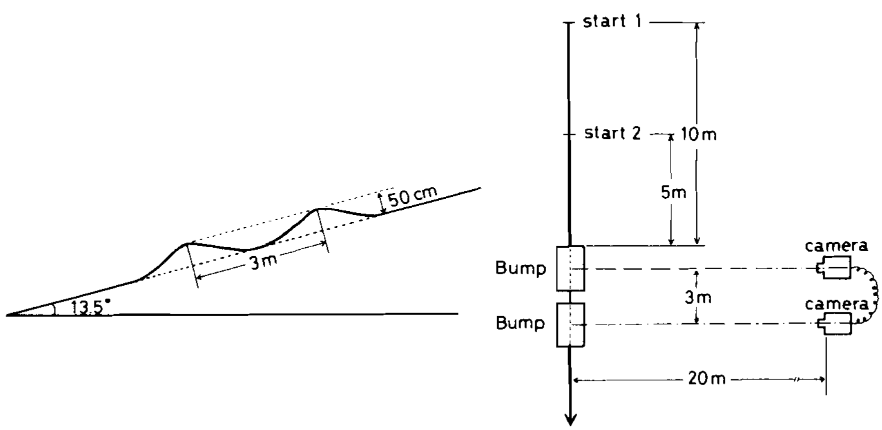

Fig. 1 Slope and bumps used for experiments 1 and 2.

Five different skill level make skiers including two highly skilled (A, B) two intermediate (C, D) skiers and one beginner (E) were employed as subjects. The highest skill level skier in the subjects was a demonstrator of Ski Association of Japan (SAJ) and the beginner had experienced skiing for 20 days. After a couple of practices for trial, each skier performed straight downhill runs over these two bumps starting from the points 5 and 10 m upward from the upper bump (the beginner started 5 m upward only). The movement of skier's body in each trial was filmed from the side using two 16 mm high speed instrumentation cameras with a speed of 100 f.p.s. Synchronization of data obtained from these two cameras was achieved by recording timing pulses on both films simultaneously.

By digitizing images on the film, coordinates of body segments were obtained. Using these coordinates, the center of gravities (C.G.) of upper, lower and whole body were calculated by segmentation method utilizing Matsui's data for Japanese (Matsui, 1958). Upper body consisted of hands, arms, head, neck and trunk, and lower body consisted of thighs, shanks and feet. Acceleration vectors of C.G. of upper, lower and whole body were obtained as second derivatives of coordinates of C.G. and root mean square of them were also calculated by the following equation:

$$\text{R.M.S. of acceleration} = \sqrt{\frac{1}{t_1 - t_2}\int_{t_1}^{t_2} |a(t)|^2 dt}$$

where a(t) is acceleration of C.G. at given time t, and t_1 and t_2 are the time the skier reached just before the first bump and just after the second bump, respectively.

Experiment 2

The procedure of this experiment was the same as of experiment 1 except for subject and camera. Four subjects the same as in experiment 1 excluding E performed straight downhill run in the same manner as in experiment 1 on a separate day. Number of camera used for recording was one. In order to analyze body movement mechanically, a four segment model linked by hip, knee and ankle joints were assumed (Fig. 2). The first segment consisted of upper body above mentioned and was approximated as rigid body. The second, the third and the fourth segment were consisted of both thighs, shanks and feet, respectively. C.G. of each segment was determined by Matsui's data for japanese (Matsui, 1958) and moment of inertia of each segment was calculated utilizing the data by Chandler et al. (1975). By solving the equations of motion applied to this model, force acting from hip joint to upper body and mechanical power generated at hip and knee joints were obtained.

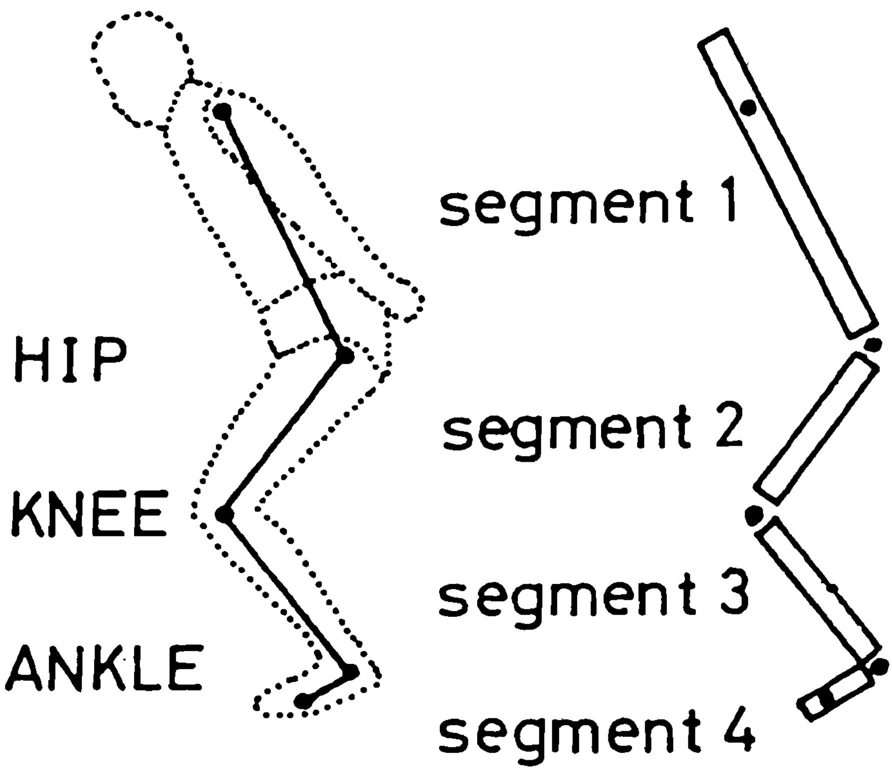

Fig. 2 Four segment link model used for mechanical analysis of experiment 2.

RESULTS

Figure 3 shows movements and acceleration vectors of C.G. of whole body together with stick pictures at every fourth frame for the trials of skier A, C and E started from 5 m upward in experiment 1. In a highly skilled skier A, the trajectory of C.G. of whole body was almost straight and the acceleration was very small throughout the run. On the other hand, in a beginner E, the trajectory was quite similar to the shape of bumps and large and rapid changes of magnitude and direction of the acceleration vectors were observed. In an intermediate skier C showed a medium tendency between the highly skilled and the beginner.

Figure 4 shows movements and acceleration vectors of C.G. of upper and lower body together with stick pictures at every fourth frame for the same trials as shown in figure 3. Although the changes of the acceleration

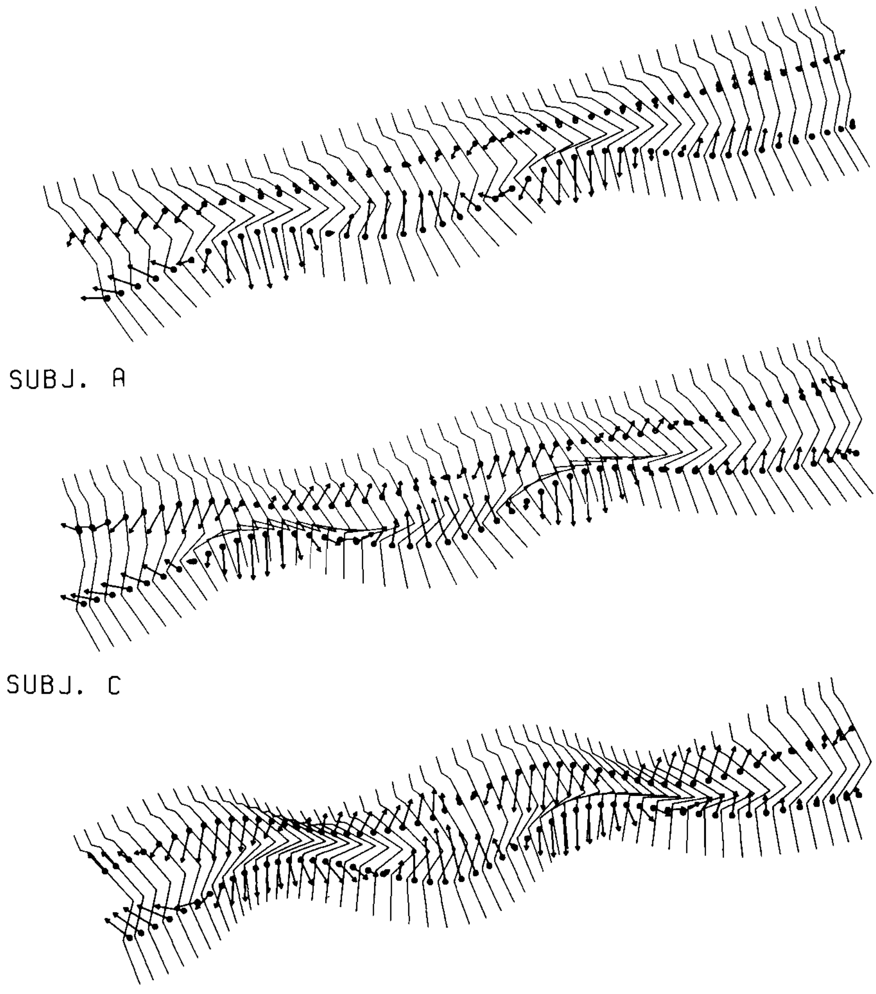

Fig. 3 Movements and acceleration vectors of C.G. of the whole body for the trials of highly skilled (A), intermediate (C) and beginner (E). Stick pictures were drawn at every fourth frame.

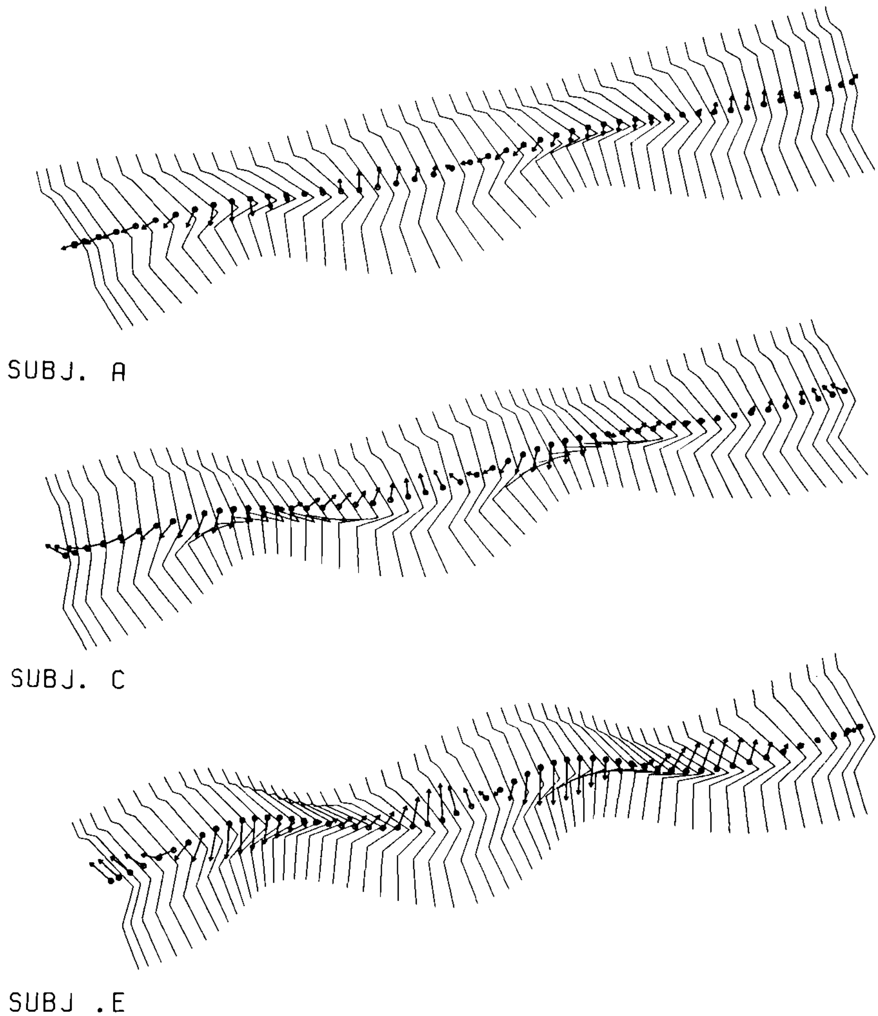

Fig. 4 Movements and acceleration vectors of C.G. of upper and lower body for the same trials as shown in figure 3. Stick pictures were drawn at every fourth frame.

of the lower body were very large in the highly skilled skier A, the trajectory of upper body still remained straight and the change of the acceleration was very small. However in the beginner E, both trajectories of C.G. of upper and lower body were not straight, and very large changes in acceleration of C.G. of both were observed.

Comparison of R.M.S. of accelerations of upper, lower and whole body for all the skiers are summarized in table 1. It is clear from the values in the table that the higher the skill level, the smaller the variation of acceleration of body. Especially, separating the whole body into upper and lower body, even though no difference was found among skiers in R.M.S. of acceleration of lower body, the R.M.S. of upper body was significantly dependent on skill level of the skier.

TABLE 1
Root mean square of acceleration of whole, lower and upper body for all the subjects

Subj.	Skill Level	R.M.S. of acceleration					
		5 m			10 m		
		Whole body	Lower body	Upper body	Whole body	Lower body	Upper body
A	Highly skilled	0.302	0.701	0.234	0.356	0.976	0.451
B	Highly skilled	0.469	0.832	0.344	0.496	1.143	0.360
C	Intermediate	0.386	0.656	0.420	0.524	1.051	0.562
D	Intermediate	0.604	0.826	0.520	0.727	1.054	0.704
E	Beginner	0.568	0.659	0.604			

Figure 5 shows the changes of joint angle, joint power and vertical component of force acting on upper body from hip joint for the trials of highly skilled (A) and intermediate (D) skiers starting from 5 m upward in experiment 2. The most evident difference observed from this figure was the changes of vertical force acting on upper body; in the highly skilled A, the amplitude of variation of the force was within 100 N while in the intermediate D, it almost reached 300 N. Changes in hip and knee joints angle indicate that both joints flexed and extended according to the skier running over a bump. Examining the difference between both

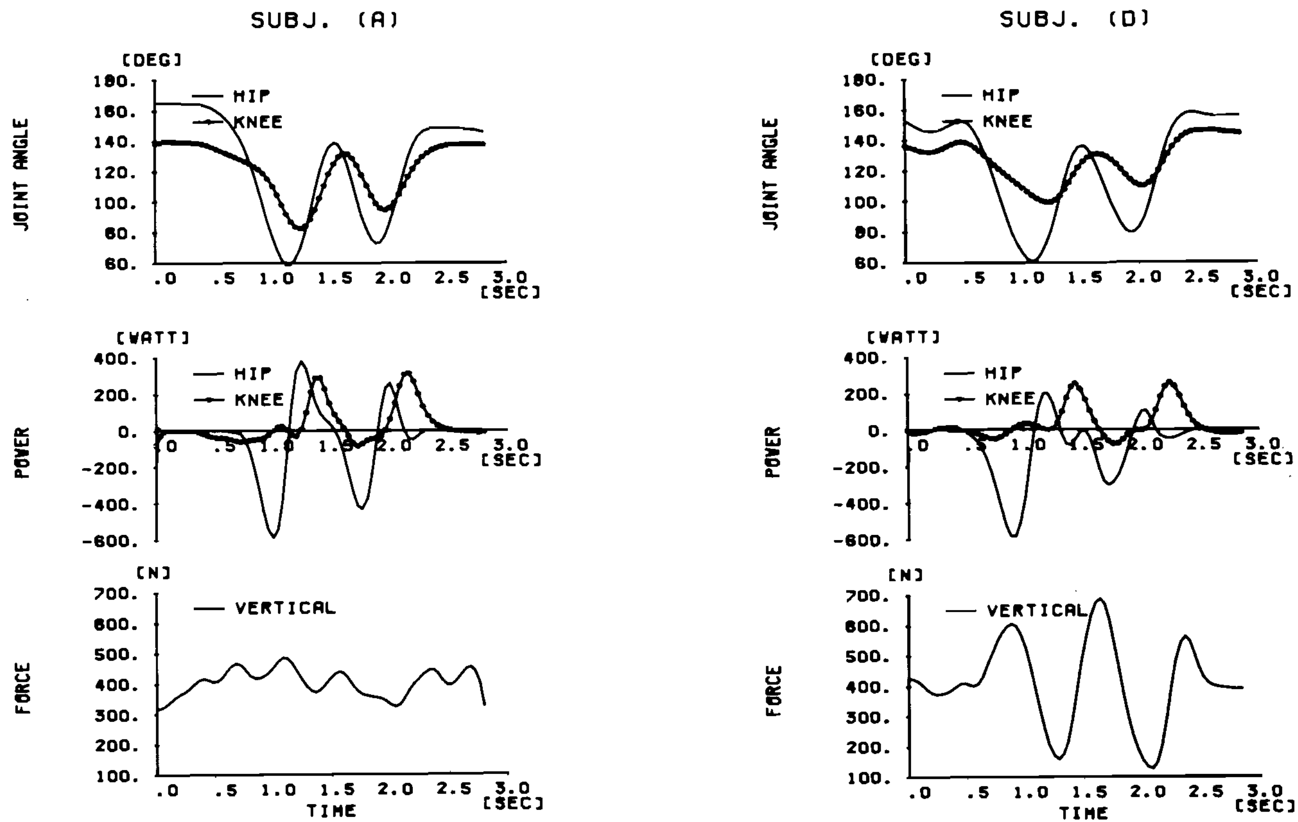

Fig. 5 Changes of joint angle, joint power and vertical component of force acting on upper body from hip joint for the trials of highly skilled (A) and intermediate skier (D).

skiers, it was observed that the range of joint angle was larger in highly skilled, especially in knee joint. Examining the changes in power at hip and knee joints, larger positive peak of power both at knee and hip joints were observed in highly skilled A, compared with those in intermediate D. A similar tendency was observed in the results of the other two skiers (one highly skilled and one intermediate).

DISCUSSION

Considering that upper body contains large mass, the results of the changes of acceleration of C.G. of upper body in experiment 1 indicated that upper body of highly skilled skier moved straight, regardless of the existence of bumps as if it had not received large force. A consistent result was also obtained from kinetic analysis of experiment 2 indicating that the highly skilled skier could avoid receiving impact from snow surface during running over bumps, while the intermediate skiers received large force under the same conditions. These result indicated that highly skilled skiers were excellent to use a certain kind of motions useful to avoid upper body receiving impulse from snow surface.

In downhill straight running both arms move only little, so upper body can be approximated as rigid body. Therefore, in straight running over bumps, only movements due to flections and/or extensions of hip, knee and ankle joint occurred. The wide range of movement of hip and knee joints agreed with the results reported by other researchers (Iizuka and Miyashita, 1979, Sodeyama et al., 1979, Ikegami et al., 1985). In the present study, in addition to kinematic analysis, movement of hip and knee joints were investigated from a mechanical points of view by calculating mechanical power at these joints. In the changing pattern of joint power, taking the angular changes of joints into consideration, positive value of power corresponded to active extension of joints and negative corresponded to passive flection. Existence of large peak values of mechanical power in the highly skilled skier can be interpreted as follows: excellent skier extends hip and knee joints actively just after he runs over the top of the bump and these active extensions of hip and knee joints make it possible to avoid his body falling and receiving impact force from snow surface after running over the bump.

CONCLUSION

Kinematic and mechanical analysis of body movements in straight downhill running over bumps was done comparing different skill level skiers. The results from this investigation concluded that a highly skilled skier is able to avoid receiving large impact force during running over bumps by his excellent shock absorbing movement, achieved by active flection and extension of hip and knee joints.

REFERENCES

Chandler, R. F., Clauser, C. E., McConville, J. T., Reynolds, H. M. and Young, J. W., Investigation of inertial properties of the human body. Report No. AMRL-TR-74-173, Wright Patterson AFB, Ohio, 1975.

Iizuka, K. and Miyashita, M., Biomechanical analysis of skiing over a hump of the skilled and unskilled skier. In: J. Terauds and H. J. Gros (eds.), Science in skiing, skating and hockey, pp. 49-54. Academic Publishers, Del Mar, 1979.

Ikegami, H., Miura, M., Ikegami, Y., Sodeyama, H. and Hashimoto, I., Kinematic analysis of body movement and stable range of balance-maintaining posture when skiing over a bump. Nagoya J. Health Physical Fitness and sports. 8:7-15, 1985.

Matsui, H., The movement and center of gravity in man. Science of Physical Education Ltd. Tokyo. (In Japanese), 1958.

Miyashita, M. and Sakurai, S., Biomechanical analysis of skiing over a hump. Proc. International Symp. on Science of Skiing. Yamagata, 1979.

Sodeyama, H., Miura, M., Kitamura, K., Ikegami, Y. and Shimaoka, K., Biomechanical analysis of postural changes over a bump during straight run skiing. Tokai Annual Report of Health and Physical Education. 1:65-72, 1979.