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Experimental Study of the Mechanism of Skiing Turns. III. Measurement of Edging Angles of Skis on Snow Surface

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By observing the track of a sliding ski during a parallel turn on a snow plane, we clarified the relationship between the direction of the ski turn and the edging angle. The relationship was the same as that observed in the experiment using a model ski sliding on a sand plane. Namely, when the angle formed between the horizontal plane and the ski, β_0, is 0°, the motion of the ski is a straight descent; when $\beta_0 \neq 0°$, it is a turning descent. If we define the edging angle as β_0, it is understood that the turning of the skis is determined only by the edging angle. The *skier's sense of making a ski turn* using his muscular strength can be explained as a matter of the perception of the skier.

KEYWORDS: ski, turning descent,edging angle

1. Introduction

The authors observed the status of a model ski sliding down a soft sand plane.[1,2] As a result, we found that the condition required for a ski to make a turn was that the edging angle β_0 satisfied $\beta_0 \neq 0°$.[2] The edging angle was not *the angle β formed between the ski surface and the sand plane*, but *the angle β_0 formed between the ski surface and a horizontal plane*. That is, $\beta_0 = 0°$ is the condition for realizing a straight descent (straight downhill run and traverse, as well as straight downhill run and traverse with side-slipping) and $\beta_0 \neq 0°$ is the condition for a turning descent. The ski turns in the direction of the edging angle β_0. Let us refer to this as the β_0-rule. In the current study, we measured edging angles β_0 for the track of a ski on a snow plane. From photographs taken successively in the experiment, we drew the locus of the ski, using the method given by T. Sahashi *et al.*[3] and then examined the relationship between the direction of the turn and the edging angles. The skis used were skis bearing a skier (skier ski) and a ski bearing an iron plate weighing 20kg instead of a skier (iron-plate ski[1])). As a result, we confirmed that the β_0-rule found in an experiment using a ski on a sand plane[2] was also observed in the experiments using skis on a snow plane. If $\beta_0 \neq 0°$ is the turning condition, then the turn of a ski should be determined by the relationship between the direction of gravity and the direction of inclination of the ski.

Judging from the many books[4,5] described about parallel turns in skiing, skiers seem to believe that the skis turn because skiers make skis turn by twisting their bodies using their muscular strength. However, in our experiments, the same β_0-rule was observed, regardless of whether or not a skier was on the ski. If the turning descent of a ski is determined only by the inclination of the ski against the direction of gravity, then the skier needs to strive to *form an edging angle β_0*, not to *turn the skis using his muscular strength.* Then, how can the *skier's sense of making a ski turn* during parallel turning be explained? In the discussion, the *skier's sense of making a turn* is explained as a problem in skier perception.

2. Experiment

2.1 *Ski and photograph*

Experiments on sliding skis was conducted using two types of skis: a skier ski and an iron-plate ski. The inclination of the ski slope α was 10°. Each ski slid down along several markers[3] located on a snow surface, and we took photographs of the ski successively. The locus of the ski was drawn from these photographs, using the method given by Sahashi *et al.*[3] The photographs were taken at 0.25 s intervals. The camera used was a 35 mm film camera with 50 mm focal length. The skier was a ski instructor certified by the Ski Association of Japan. The angles α and β_0 were measured using an angle gauge.[2] The length of the skis was 200 cm. Hereafter, the trail left on the snow surface by a sliding ski is referred to as a track, and the location of a ski obtained from an analysis of photographs is referred to as a locus.

2.2 *Edging angle β_0*

Figure 1 shows a ski slope. α represents the inclination angle and PQ represents the fall line of the ski slope. A one-legged skier slides down through the points S, O and T on the slope DGFB. The area JIHC represents an enlarged part of the sliding surface at point O. The ski, abcd, is on the sliding surface. The sliding direction HC is a tangent of the turning-descent line S, O and T. Generally, the direction of the ski and direction of

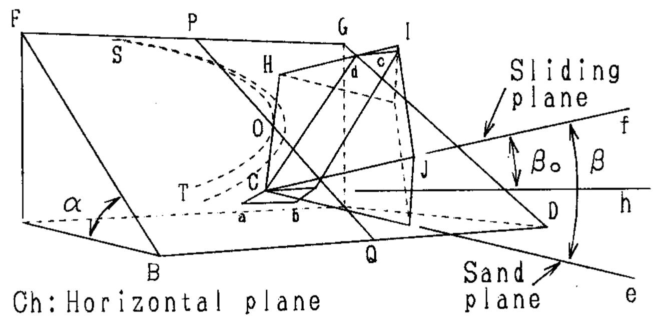

Fig. 1. Edging angle β_0 (angle between ski and horizontal plane). Edging angle β (angle between ski and slope). α is the inclination of the slope.

the ski's descent are not identical, as seen in this figure. Line Ce is on the slope DGFB. Line Cf is on the sliding plane, which is inclined by an angle β from the slope. Line Ch is on the horizontal plane, which is inclined by an angle β_0 from the sliding plane. When $\beta_0 > 0°$, the ski makes a right turn. When $\beta_0 = 0°$, Cf equals Ch and the ski makes a straight descent in the direction HC. When $\beta_0 < 0°$, the ski makes a left turn. This illustrates the β_0-rule, where the angle β_0 is the edging angle (angle between a ski and the horizontal plane) which determines the nature of a turn.[2)]

2.3 *Descending angle of traverse*

In the case of a traverse, the inclination of the slope is expressed as in Fig. 2. α is the inclination angle of the slope. CB represents a fall line. With respect to a skier who traverses in the direction CG, ϕ, δ and ψ are defined as shown in the figure. ϕ is the diagonal angle of traverse. δ is the descending angle of traverse. ψ is the apparent inclination angle of the slope. In the Fig. 2, we let CB=1, DB $= a$, EF $=$ CD $= b$, BE $= c$, FB $= d$, DG $= f$, KG $= g$, CE $= h$, JG $= j$ and DK $= k$. If we set $c = \cos\alpha$, $a = 1/\cos\phi$, $c^2 + h^2 = 1$, $a^2 = b^2 + 1$, $d^2 = b^2 + c^2$, $\tan\psi = h/d$, $f = b \cdot \tan\phi$, $g = f \cdot \cos\alpha$, $j^2 = b^2 + g^2$, $k = f \cdot \sin\alpha$ and $\tan\delta = k/j$, ψ and δ can be obtained from α and ϕ.

$$\psi = \tan^{-1}(h/d) = \tan^{-1}\{\sqrt{[(1-c^2)/(b^2+c^2)]}\},$$
$$\delta = \tan^{-1}(k/j) = \tan^{-1}\{f \cdot \sin\alpha/\sqrt{(b^2+g^2)}\}.$$

2.4 *Snow surface and β_0*

When a skier makes a straight downhill run with open legs, and the legs and skis perpendicular to each other, the status of the legs and skis observed from behind is as shown in Fig. 3(a). Here, AD and AB represent the length of the legs. ECF is the horizontal plane (snow surface). Angle θ is half of the angle between the legs, which is equal to the angle β_0 between the snow surface and the surface of the ski.

From actual measurements of straight downhill runs with open legs, as shown in Fig. 3(b), the left and right skis were edged inwards and $|\beta_0| < |\theta|$. As shown in this figure, in the case of skiing with two legs, the edging angle of the right ski is defined as $\beta > 0°$, and that of the left ski is defined as $\beta < 0°$. This figure is a cross-sectional drawing of skis observed from behind.

2.5 *β_0 in traverse*

Figure 4 shows results of an experiment on traverse with open legs. The angle between the starting direction of the ski and the fall line was 70°(ϕ = 20°). In the figure, (a) represents the locus of the ski. (c) is a bar graph representing values of β_0 of the left ski. (d) is a bar graph representing values of β_0 of the right ski. From Fig. 4, we can see that the left and right skis are almost symmetrically edged against the horizontal plane, although the snow plane has an inclination. As a result, the edging angle to the snow plane of the left ski $|\beta|$ is larger than that of the right ski $|\beta|$. This is indicated by the shadow of the skis in Fig. 5. The status of the skis is illustrated in Fig. 3(c). The apparent inclination perpendicular to the sliding direction ψ is about 9°. In Fig. 4, if we define the sum of values of β_0 for the left and right skis as β_{0s}, β_{0s} approaches 0° for all loci. In the case of traverse with closed legs (same condition as in Fig. 4), the left and right skis were almost symmetrically edged ($\beta_{0s} = 0°$).

Figure 6 shows a one-legged traverse (same condition as in Fig. 4). The circles represent the locations where $\beta_0 = 0°$. In most parts of the track, β_0 is almost 0°.

Table I shows values of β_0 for the three above-mentioned cases of traverse. β_0 is represented with absolute values. The central width (defined as the distance between the center of the right ski and that of the left ski) in the case of open legs is approximately 40cm. The central width in the case of closed legs is approximately 20cm. The length of the legs is 90cm. From Table I, we

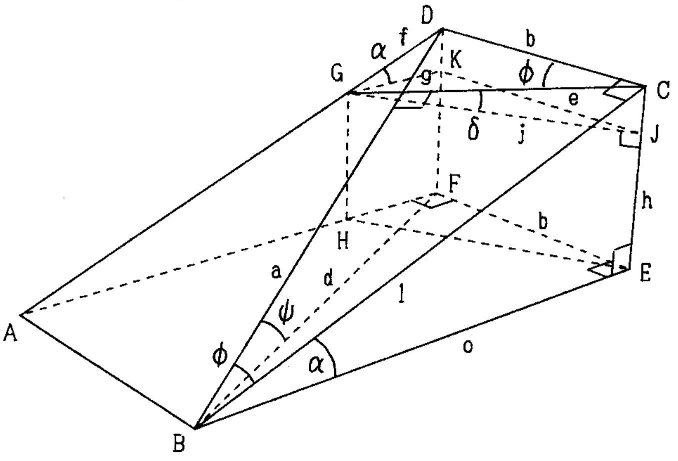

Fig. 2. Inclination of traverse. α is the inclination of the slope. ϕ is the diagonal angle of traverse. ψ is the apparent inclination of the slope. δ is the descending angle of traverse. CB is a fall line.

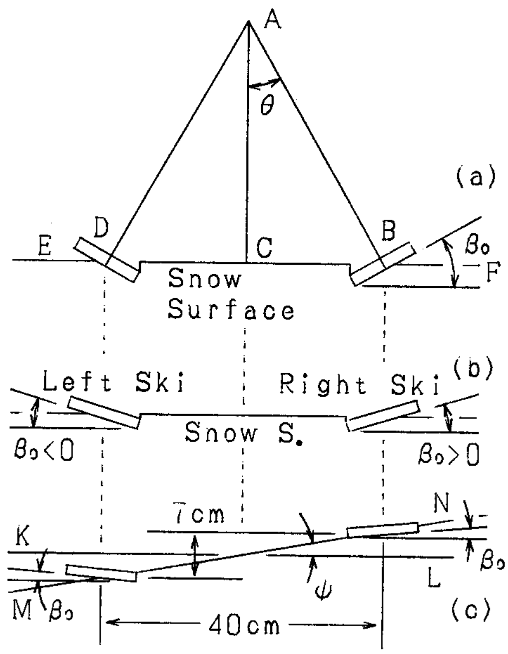

Fig. 3. Edging angle. (a) Leg is perpendicular to the ski. ECF represents snow surface. (b) Positive and negative edging angle β_0. (c) Edging angle β_0 in case of traverse with open legs. MN is snow surface. KL is horizontal plane. ψ is the apparent inclination of the slope.

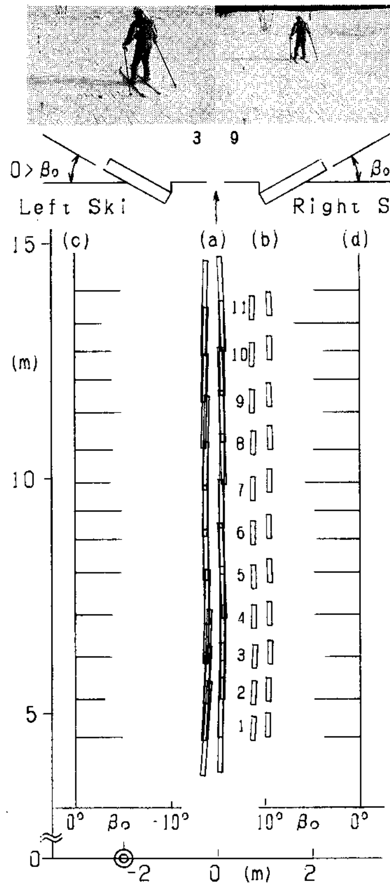

Fig. 4. Loci of skis while traversing with open legs and β_0. ◎ is the position of the camera. (a) Locus of the skier ski. Since the locus shown in (a) is difficult to distinguish due to overlap, the same locus is drawn in (b), 1m to the right, with a ski length of 50 cm. (c) Values of β_0 of the left ski. (d) Values of β_0 of the right ski. The arrow above (a) shows the direction of descent. Division of the vertical axis is common to locus and edging angle. Photograph numbers correspond to ski numbers.

Fig. 5. Observing the shadow of the skis, edging angle β of the left leg against the snow surface appears larger than that of the right leg. This figure corresponds to Fig. 3(c) and the case of ski number 1 in Fig. 4.

can see that the edging angle β_0 is proportional to the angle θ, and values of β_0 are approximately half of θ.

2.6 *β_0 in parallel turn*

Figure 7 shows the locus of the skis in the case of a parallel turn with closed legs, and the measured values of β_0. In this case, the skier slid down using a so-called *carving turn* in order to make a track of the descent, since the *carving turn* involves little side skidding. Numbers 1–5 show the status of a straight downhill run, where the skis are edged inwards. Values of β_0 are similar to those in the case of a traverse with closed legs as described in §2.5. Values of β_{0s} are also almost 0°. The skier begins an uphill turn from number 6, and the values of β_0 of the right ski begin to increase; those of the left ski change from negative to positive. For both skis, $\beta_{0s} > 0°$. Number 10 is the point of inflection at which the motion changes from an uphill turn to a downhill turn. Values of edging angles of the left and right skis become symmetrical at this point, and $\beta_{0s} = 0°$. The downhill turn begins from number 11, and the edging angle of the left ski increases while that of the right ski decreases; $\beta_{0s} < 0°$. Thus, β_{0s} becomes 0° in a straight downhill run or at the point of inflection of the ski track; $\beta_{0s} \neq 0°$ in a turning descent. From and after number 12, no track of the ski was observed since the degree of side skidding of the ski increased; therefore measurement of β_0 was impossible.

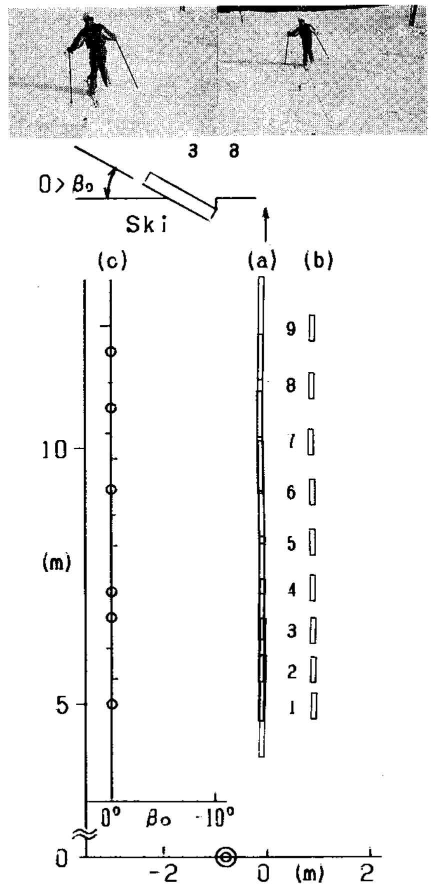

Fig. 6. Locus of a ski in one-legged traverse and β_0. Circles in (c) represent results in the cases of $\beta_0 = 0°$.

Table I. Ski's central width and edging angle β_0 and β_{0s}. $\alpha = 10°$, $\phi = 20°$, $\Psi = 9.4°$, $\delta = 3.4°$.

Central width		β_0	θ	β_{0s}
Fig. 4	40 cm	$5° \pm 1°$	12°	$0° \pm 1°$
—	20 cm	$3° \pm 1°$	6°	$0° \pm 1°$
Fig. 6	—	$0° \pm 1°$	—	—

Figure 8 shows the ski locus for a one-legged descent and the corresponding values of β_0. The skier makes a

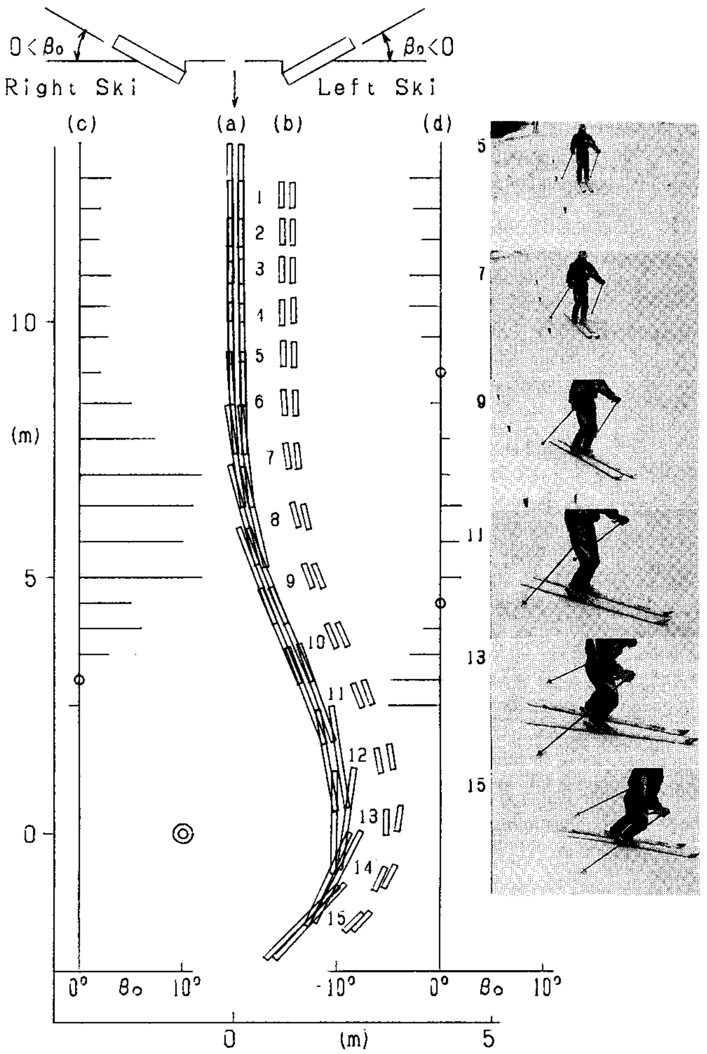

Fig. 7. Loci of skis in a turning descent with closed legs and β_0.

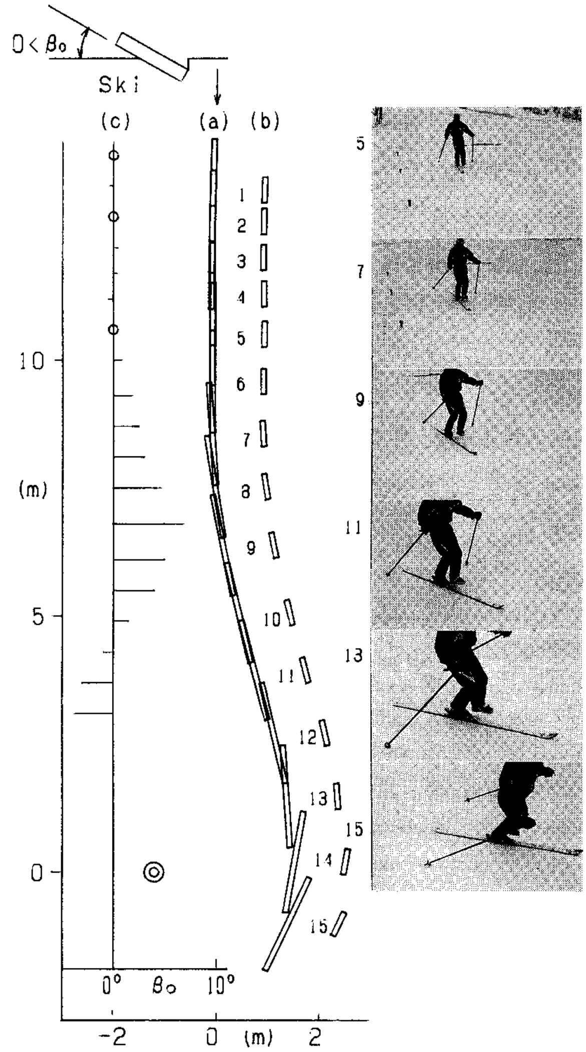

Fig. 8. Locus of a ski in one-legged turning descent and β_0.

straight downhill run in the from numbers 1 to 5. The point of inflection exists between numbers 10 and 11. Numbers from 6 to 9 show an uphill turn, and numbers from and after 11 show a downhill turn. From the figure, we can see that $\beta_0 = 0°$ for a straight downhill run and at the point of inflection, and $\beta_0 \neq 0°$ for a turning descent.

2.7 *β_0 of iron-plate ski*

Figure 9 shows the locus of the iron-plate ski and results of measurement of β_0 values. In the case of the iron-plate ski, an iron plate weighing 20 kg was placed on the binding instead of a ski boot.[1] In order to change the center of gravity of the iron-plate ski, the position of the iron plate was changed in the direction perpendicular to the ski length. At the starting point, the iron-plate ski was set in the direction of the fall line (arrow) to begin the descent. The ski turned in the direction of deviation of the ski's center of gravity. Figure 10 shows the radius of curvature obtained from a locus of the iron-plate ski and result of measurement of β_0 value. (When the center of gravity was changed, a locus with a different radius of curvature was obtained.) The values of β_0 are absolute values. The outer circles in the figure show the range of measurement errors. As the value of β_0 increases, the radius of curvature decreases in the figure. At the position marked * $\beta_0 < 1°$, and the track was almost a straight line. Therefore, in the case of the iron-plate ski as well, a value of $\beta_0 = 0°$ is obtained in a straight descent and $\beta_0 \neq 0°$ in a turning descent.

2.8 *β_0 of model ski*

Figure 11 is a revision of a drawing presented in another paper by the authors.[2] The figure shows loci of a model ski sliding down a sand plane, and the corresponding values of β_0 ($\alpha = 26°$). From this figure, it can be seen that $\beta_0 = 0°$ in a straight descent and at a point of inflection, and $\beta_0 \neq 0°$ in a turning descent.

3. Discussion

3.1 *β_0 rule*

A one-legged traverse (Fig. 6) and part of a straight downhill run (numbers 1–5 in Fig. 8) correspond to a straight descent, where $\beta_0 = 0°$. In the case of a two-legged traverse with open legs (Fig. 4) and part of a straight downhill run (numbers 1–4 in Fig. 7), the skis are edged symmetrically and $\beta_{0s} = 0°$. In this case, a straight descent seems to have been possible when the left and right skis were edged in opposite directions with the same magnitude. In part of the one-legged turning descent (Fig. 8), $\beta_{0o} \neq 0°$; in part of the two-legged turning descent (Fig. 7), $\beta_{0s} \neq 0°$. (Here, parts of the straight downhill runs and the points of inflection are classified as a straight descent.) In terms of the β_0-rule, the above-mentioned results, including the results of the