

The Kinetics of Judo

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The principles of judo may be well expressed by the proverb, "meekness overcomes strength". In other words, a person with an inferior physical strength may, with the aid of judo, be able to overcome a person far superior in physical strength. Now, what is the

rationale which makes possible this "meekness over-coming strength". In order to make scientific investigations on the principles underlying the various techniques used in judo, we first analyzed the techniques, and made observations on their kinetics, and further wish to synthesize by adding psychological and physiological investigations. Among the throwing techniques, a few typical ones were selected, and serial photographs of the performers in action were taken by means of a high speed camera. Each serial photograph was carefully analyzed, and the kinetic principles of the techniques studied.

Photography was made with a 16mm camera with a speed of thirty two frames per second. The techniques studied were; from among the waist technique, Harai-goshi, Tsurikomi-goshi; from among the hand technique, Seoi-hage, Kata-guruma; from among the foot technique, Hiza-guruma; Osoto-gari; from among the Ma-sutemi technique, Tomoe-nage; and from among the Yoko-sutemi

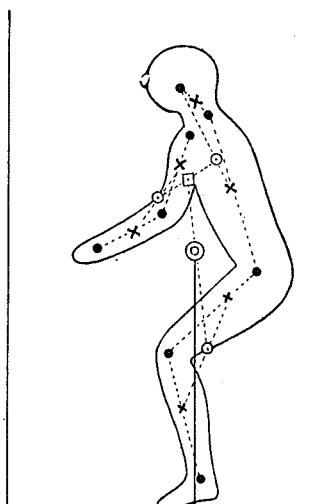


Fig. 1. Knoll's method for determining the centre of gravity

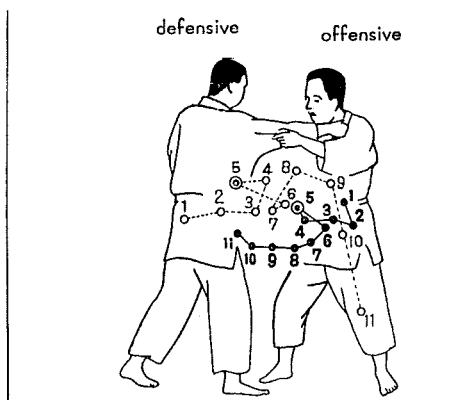


Fig. 2. Seoi-nage

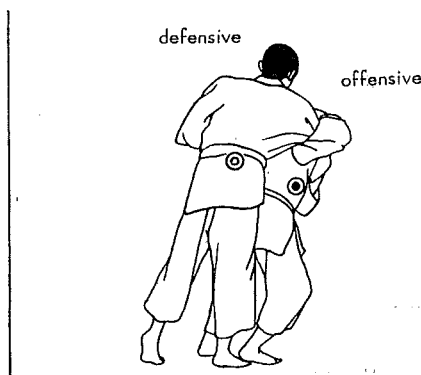


Fig. 3. The moment the trick is put on.

technique, Uki-waza. The performers were selected from the students of the Tokyo University of Education, namely: Iida, Higuchi (both fifth grade), Kodama, Enomoto (both third grade) and Matsumoto (eighth grade). Photographs were taken from the side and from above. From these serial photographs the centres of gravity were measured according to Knoll's construction method, and the following results and conclusions were obtained.

I. The Relation Between the Locus of the Centre of Gravity and the Kuzushi, Tsukuri, and Kake

(Note) The loci of the offensive and the defensive are indicated by a continuous line and a dotted line respectively. \odot and \ominus indicate the centres of gravity of the offensive and the defensive respectively, at the instant the trick is put on (Fig. 2). The figures near the loci show in order the transitions of the centres of gravity taken at 5/32 sec intervals.

(1) Hand Technique—Seoi-nage (offensive: Matsumoto, defensive: Kodama)

a) As shown in Fig. 2, the locus of the defensive from 3 to 5 is suddenly raised. This shows that whilst the defensive advances he is drawn in, and unbalanced. No significant changes in the locus of the offensive from 4 to 5 is observed. This indicates that the offensive while diminishing the space between him and the defensive profitably uses the momentum of the defensive, and by using both hands draws him in, imparting a rotary motion with the breast of the defensive as the fulcrum.

b) The locus of the offensive after the trick is put on is lowered, whilst that of his opponent is raised. This

shows that the offensive after drawing in his opponent, rotates the latter by means of the resultant force caused by the forward bend of the body, and the stretching of the knees.

(2) Hand Technique—Kata-guruma (offensive: Higuchi, defensive: Enomoto)

The knack of a successful Kata-guruma is in bringing the centre of gravity of the offensive directly under that of the defensive thus making possible for the offensive to carry the defensive on his shoulders without much effort.

a) The sudden drop in the locus of defensive from 3 to 4 indicates that he has been unbalanced forward. On the other hand the locus of the offensive falls from 3 to 4 reaching its lowest at 5. The relative positions of the two centres of gravity at the moment the trick is put on are at 5. The loci

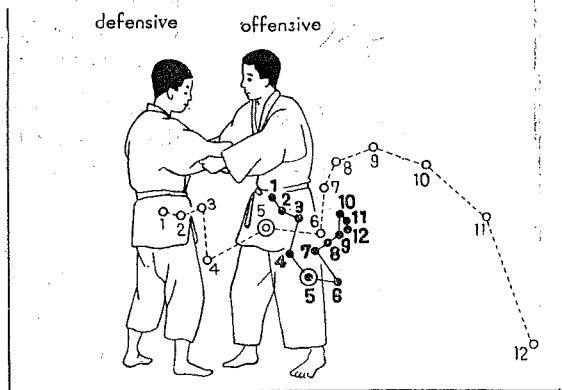


Fig. 4 Kata-guruma

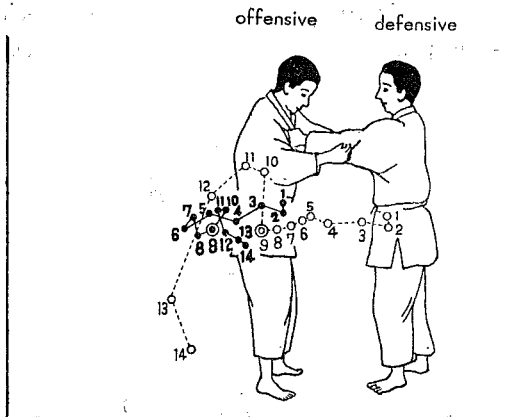


Fig. 5 Harai-goshi

hand the locus of the offensive falls from 3 to 4 reaching its lowest at 5. The relative positions of the two centres of gravity at the moment the trick is put on are at 5. The loci

of both the offensive and the defensive from 6 to 9 rise suddenly, indicating that the trick has been put on well in accordance with the laws of kinetics.

(3) Waist Technique—Harai-goshi (offensive: Matsumoto, defensive: Higuchi)

a) When the defensive is unbalanced forward, his locus moves nearly horizontally until the trick is put on at 9. Note the differences in the loci of the defensive of each trick so far mentioned, while the defensive is being unbalanced. The locus of the offensive while shortening the space between him

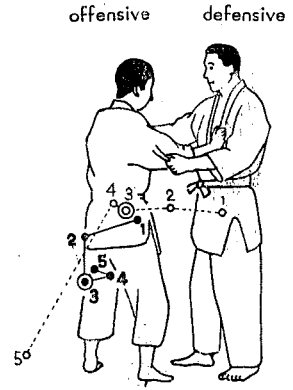


Fig. 6 Tsurikomi-goshi

and his opponent retreats horizontally and thus the defensive is unbalanced.

b) After bringing the defensive into positions 8 and 9 the offensive also lowers his centre gravity (8, 9), and puts on the trick while carrying his opponent on his hip, forcibly sweeps up his opponent.

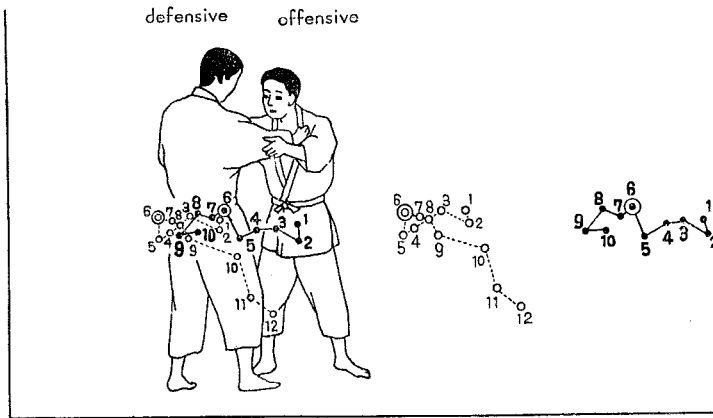


Fig. 7 Hiza-guruma

(4) Waist Techni-

que—Tsurikomi-goshi (offensive: Matsumoto, defensive: Kodama)

a) The locus of the defensive advances horizontally until the trick is put on at 3. Theoretically this locus should show an upward curve, as the main point of the Tsurikomi-goshi is to draw in the defensive and carry him on the hip. As depicted in Fig. 6, when the locus from 1 to 2 does not show an upward curve, there results a certain amount of resistance, and the unbalancing of the defensive cannot be carried out smoothly.

offensive defensive

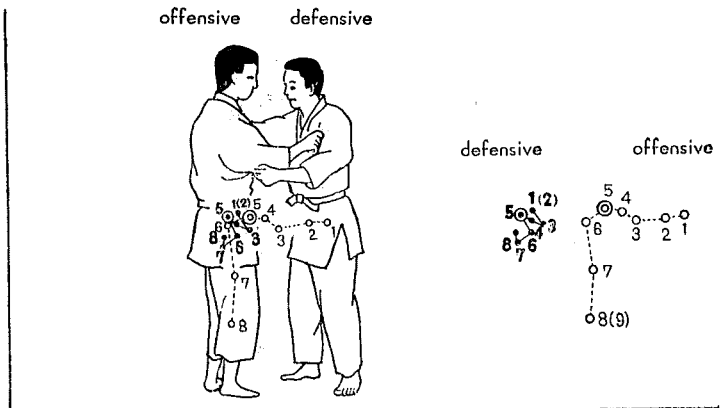


Fig. 8 Osoto-gari

b) The loci of the offensive and the defensive 3, 4, 5 show that the centre of gravity of

b) The loci of the offensive and the defensive 3, 4, 5 show that the centre of gravity of

the offensive is brought under that of his opponent. With the front part of his opponent's hip

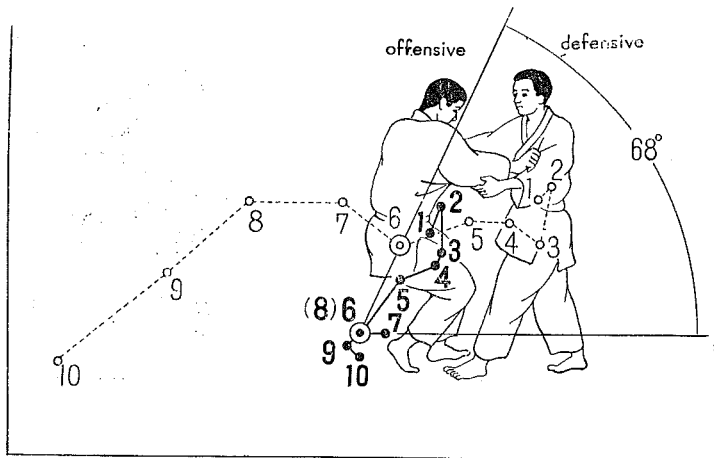


Fig. 9 Tomoe-nage

is a sudden upward trend in the loci of both the offensive and the defensive from 5 to 9, which show that the body of the defensive is raised and unbalanced. The loci indicate the rational timing of the offensive in putting on the trick.

b) After putting on the trick, the offensive by using both hands twists his opponent, resulting in the latter's rotary motion with his knee as the fulcrum. This relation may be clearly observed from the loci of the performers.

(6) Foot Technique—Osoto-gari (offensive: Iida, defensive: Kodama)

a) The defensive is unbalanced to his right side while being made to advance with his left foot.

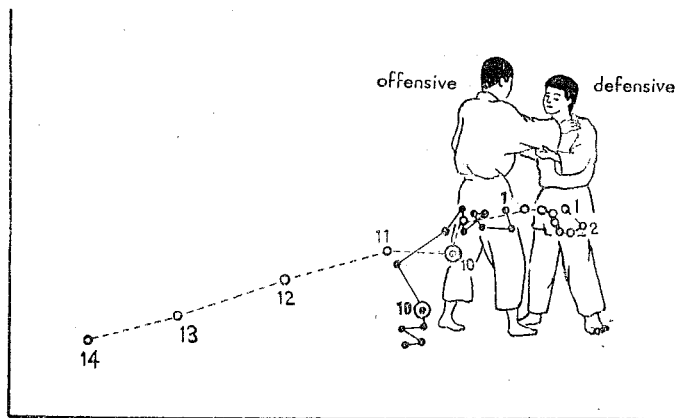


Fig. 10 Uki-waza

Thus his weight is on his right foot. The locus described is 1, 2, 3. Locus 3, 4, 5 is the locus described when the defensive's body is lifted.

b) At the highest point of the locus of the defensive the trick is put on. At the moment the offensive sweeps his right leg, he lowers his centre of gravity, whilst the defensive after being swept is thrown down as is shown by the locus of the centre of gravity.

(7) Ma-sutemi Technique—Tomoe-nage (offensive: Matsumoto, defensive: Kodama)

a) Fig. 9 shows the loci of both the offensive and the defensive in the typical Ma-sutemi technique, Tomoe-nage, in which the offensive, while drawing the opponent towards him brings his centre of gravity far below that of his opponent.

b) After the trick is put on, the locus of the defensive is higher and more elongated than, with the other tricks showing that the defensive is thrown farther than with most other tricks.

(8) Yoko-sutemi Technique—Uki-waza (offensive: Iida, defensive: Higuchi) From the

pressed against the back part of his own hip, and with the offensive's hip as the fulcrum, the defensive is rotated and thrown down.

(5) Foot Technique—Hizaguruma (offensive: Matsumoto, defensive: Iida)

a) The loci of the defensive and the offensive as far as 6 are nearly identical. There

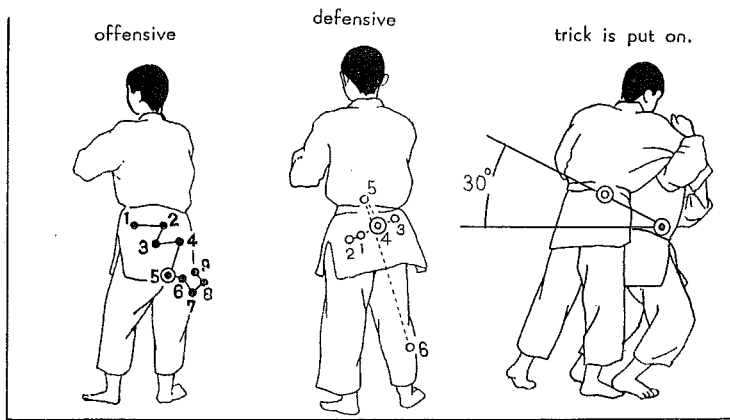


Fig. 11 Seoi-nage

into the adequate position, the offensive by quickly dropping himself puts on the trick. This action may be clearly seen from the sudden downward trend in the locus of the offensive.

b) The sudden drop from 9 to 10 in the locus of the defensive is worthy of notice, because if the procedure until the trick was put on, had been carried out ideally, the locus of the defensive from 7 to 12 should have described a more smooth curve. This disturbance in the locus of the defensive is probably due to the forward shift from 9 to 10 in the locus of the offensive, which implies that there is further need for research in the manner of the offensive when he drops himself.

zigzag locus of the opponent (Fig. 10), it is evident that the offensive by making the defensive advance toward him tries to unbalance him in his front right side. The curved locus 6, 7, 8, 9, of the defensive indicates that he, while his motion is being accelerated is unbalanced forward. After bringing the defensive

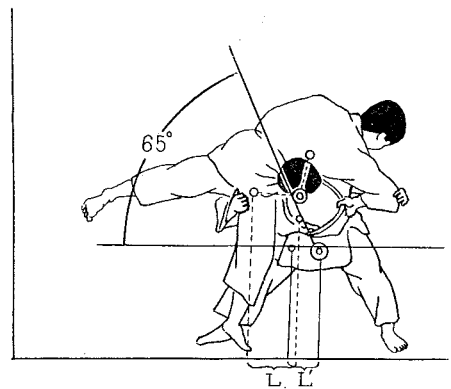


Fig. 12 Kata-guruma

II. The Relation between the Effectiveness of the Tricks and the Centre of Gravity

(1) Seoi-nage (Ippon-seoi). In this technique, the offensive throws down his opponent using a rotary force with his shoulder as the fulcrum. This force is a resultant of the combined forces of the offensive's bodily twist, the push at the knees, and the forward bend of his body.

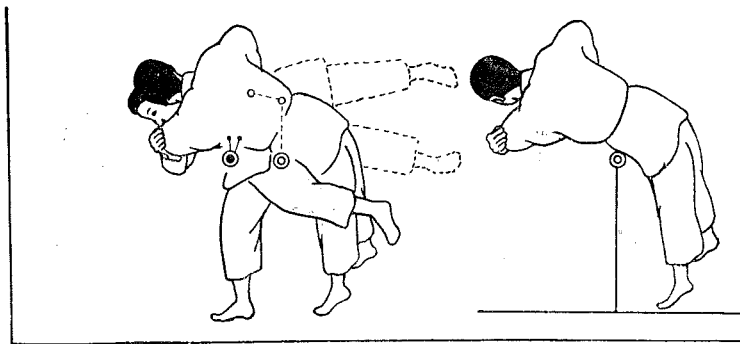


Fig. 13 Harai-goshi

combined forces of the offensive's bodily twist, the push at the knees, and the forward bend of his body.

a) As indicated in Fig. 11, the angle formed by the line joining the centres of gravity of the offensive and his oppon-

ent, and a horizontal line is approximately 30° . This angle from the point of view of kinetics should be more obtuse, but as it is necessary for the offensive's right arm to fix the defensive's breast, this is not quite possible. The lack in the magnitude of the angle is well compensated by the forward momentum of the defensive.

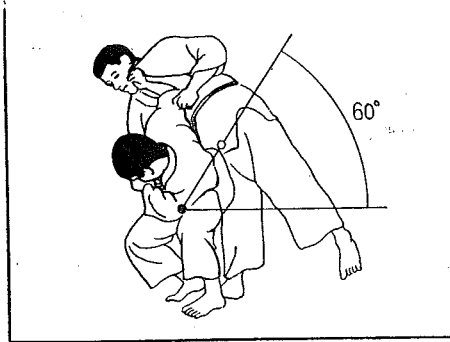


Fig. 14 Turikomi-goshi

At this moment, the important point is the angle formed by the line joining the centres of gravity of the performers and the horizon. From the standpoint of kinetics the most effective angle is 90° , i. e. when the centre of gravity of the defensive is directly over that of the offensive. However, when other factors are taken into consideration, such as the utilization of the forward momentum of the defensive, the pull of the offensive's right arm helped by that of his left arm, an angle of approximately 65° (Fig. 12) is appropriate.

b) The offensive in order to set himself in a proper position to put on the trick, lowers his centre of gravity while drawing in his opponent, and thus makes the distance between the two centres of gravity wider.

(2) Kata-guruma. a) After unbalancing the defensive and putting on the trick in a low position, the offensive lifts his opponent on his

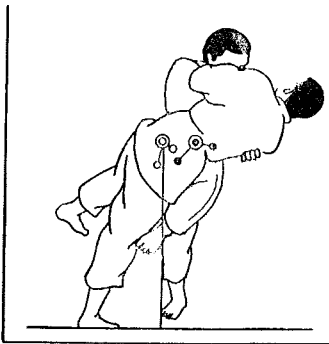


Fig. 15 Hiza-guruma

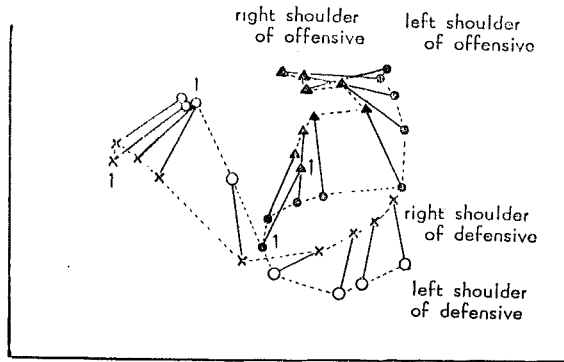


Fig. 16 Hiza-guruma

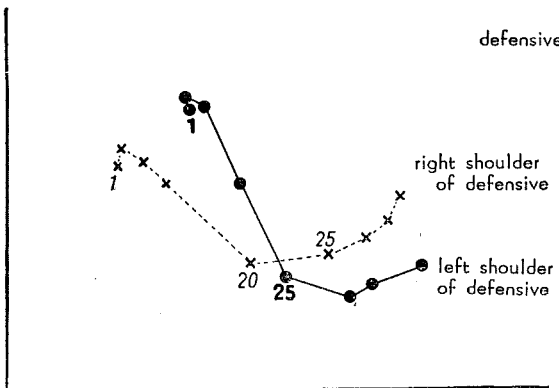


Fig. 17 Hiza-guruma



Fig. 18 Hiza-guruma

b) Now, let us consider the shift in the positions of the centres of gravity $5/32$ sec. after the trick is put on (L, L' in Fig. 12). L seems to be quite adequate, but the shift L' appears to be slightly wider than it should be. It is suggested here, that L' be shortened a little, and also the upper half of the bent body of the offensive be straight-

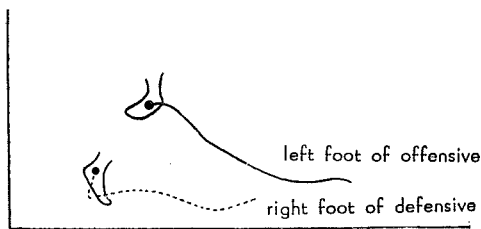


Fig. 19 Hizaguruma

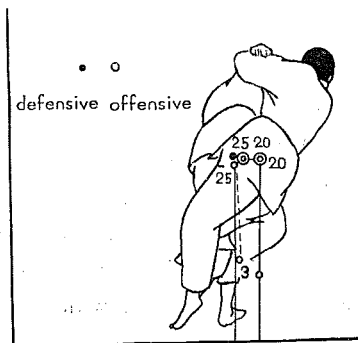


Fig. 20 O-sotograi

ened. Since the resultant of the forces which straighten the knees, and the pull of the hands, especially that of the left hand, making the shoulder as the fulcrum rotates the defensive and forms the force which makes the Kata-guruma effective, it may be inferred that a too wide L' is undesirable.

(3) Harai-goshi. a) The Harai-goshi as evident from Fig. 13 consists in unbalancing the defensive forward, and his line of the centre of gravity is thrown far out of the basic plane. From the standpoint of kinetics, this form is not possible, but actually it is made possible by the fact that the offensive makes use of the judo costume of the defensive. This is an important factor which must be taken into consideration in the act of unbalancing in all the other techniques of judo. Further, it may be seen in Fig. 13 that the opponent is in the form of a rigid body.

b) The effectiveness of the Harai-goshi depends on the proper combined action of the pull of the hand after lifting the defensive on the offensive's hip, the twisting action of his body, and the upward sweep of his leg. Fig. 13 shows that the defensive's centre of gravity is lifted way upwards.

(4) Tsurikomi-goshi. a) In this technique, the offensive in order to lift his opponent after carrying the latter on the back side of his hip, must bring his centre of gravity under that of his opponent. The angle at this point which is 60° compared to the 65° in the Kata-guruma, and the 68° in the Tomoe-nage in smaller. These differences in the angles depend upon the positions of support, but the magnitude is usually between 60° and 70° . The offensive in order to bring his opponent into the proper position, must lay stress on

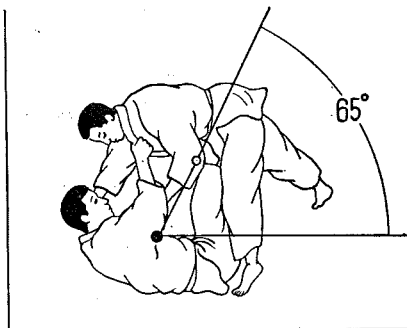


Fig. 21 Tomoe-nage

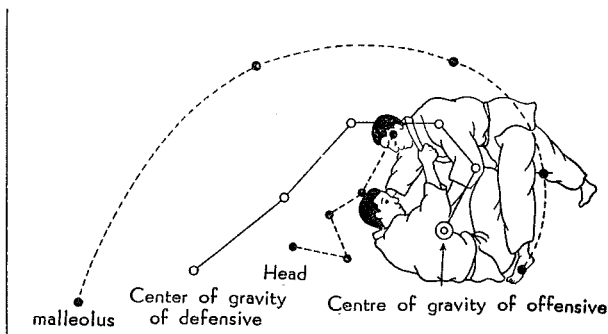


Fig. 22 Tomoe-nage

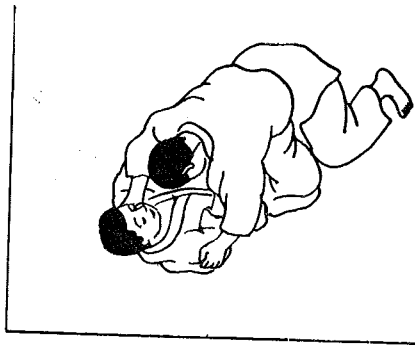


Fig. 23 Putting on the trick (Tomoe-nage)

the manner in which he draws in his opponent, and also on his knee movements.

b) The further forward the centre of gravity of the defensive is shifted, the more effective becomes the pull of the offensive as he draws in his opponent. Also, the friction between the defensive's heels and the tatami (floor) is lessened, and results in a neat performance. Hence, the success of this technique depends upon the manner in which the offensive draws in his opponent.

(5) Hiza-guruma. a) As seen in Fig. 15 the line of the centre of gravity is thrown

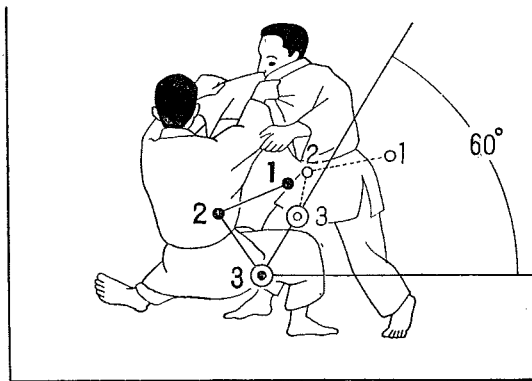


Fig. 24 Uki-waza

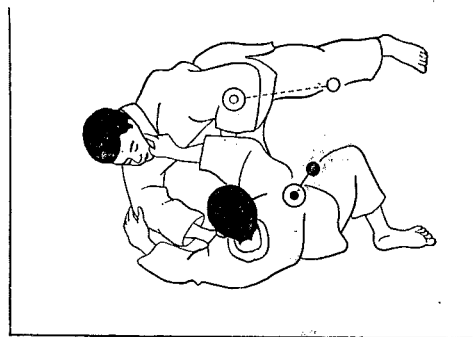


Fig. 25 Uki-waza

far out of the basic plane. The offensive after unbalancing his opponent, is about to twist him, making his left foot as the fulcrum.

b) The twisting action follows directly after the position depicted in Fig. 15. This procedure may be inferred from Figs. 16, 17, and 18 which were constructed from photographs taken from above.

c) The movements of the left foot of the offensive and the right foot of the defensive are shown in Fig. 19, as the loci of the ankle bones of the performers. From the figure, the following facts may be understood: (i) The upward shift of the defensive's right foot indicates that he is being unbalanced forward and gaining momentum forwards. (ii) From the locus of the left foot of the offensive, his intention to move his left foot as little as possible may be inferred. The rather irregular line described towards the end has

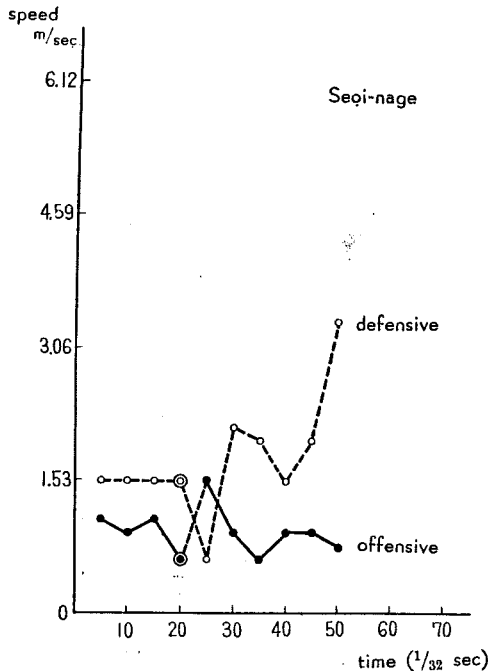


Fig. 26 Seoi-nage

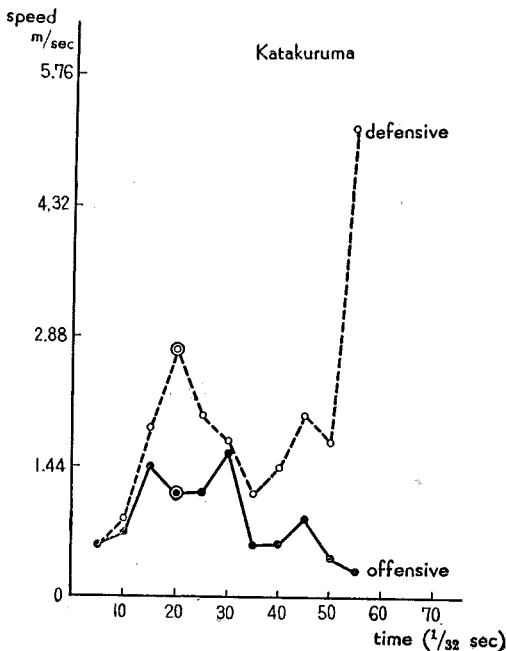


Fig. 27 Kata-guruma

a close relation to the upward and downward movement of defensive's right foot, and indicates the subtlety of the technique.

(6) Osoto-gari. a) The combined forces of the push of the offensive's right hand, and the sweep of his right leg act as a couple upon the defensive, after the latter has been unbalanced toward the right rear corner. This may be seen in Fig. 20 in which the centres of gravity at 20/32 sec. and 25/32 sec. are fixed nearly at the same point.

b) After the trick is put on, the defensive falls perpendicularly. It very often happens that the offensive uses unreasonable force and pushes down the defensive, in which case the shift of the centre of gravity from 20/32 sec. to 25/32 sec. becomes wide. Fig. 8 shows the ideal loci described in the performance of the Osoto-gari.

(7) Tomoe-nage. a) Fig. 21 shows the readied position to put on the trick, with the relative positions of the centres of gravity of the offensive and the defensive at 65°. It may be understood from this posture that the forward momentum of the defensive is to be utilized. One very often observes during a match that the defensive in order to prevent this lowers his body, thus arresting his forward movement.

b) This technique is an application of the principle of the lever. The force which throws the defensive is the result of the harmonious combination of the pull imparted when the offensive drops himself down, and the kick applied to the defensive's abdomen. In Fig. 22 are shown the loci of the defensive's centre of gravity, the centre of his head, and his left ankle bone.

c) The significance of the Ma-suteni technique may be understood from Fig. 23 which was taken from above.

(8) Uki-waza. a) The effective force in this technique is the resultant of the mo-

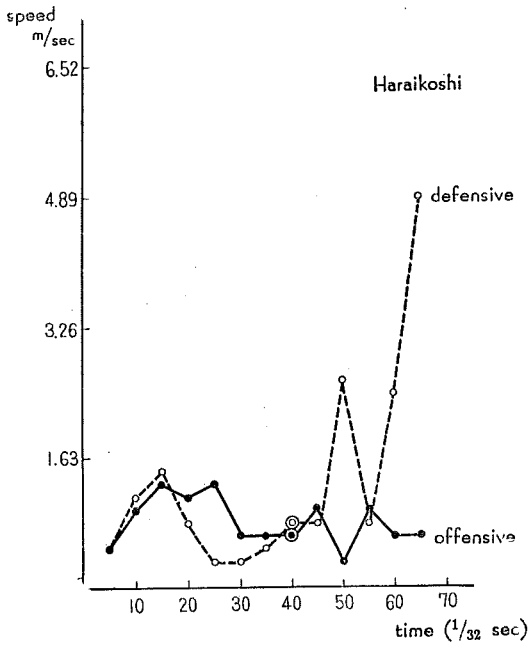


Fig. 28 Harai-goshi

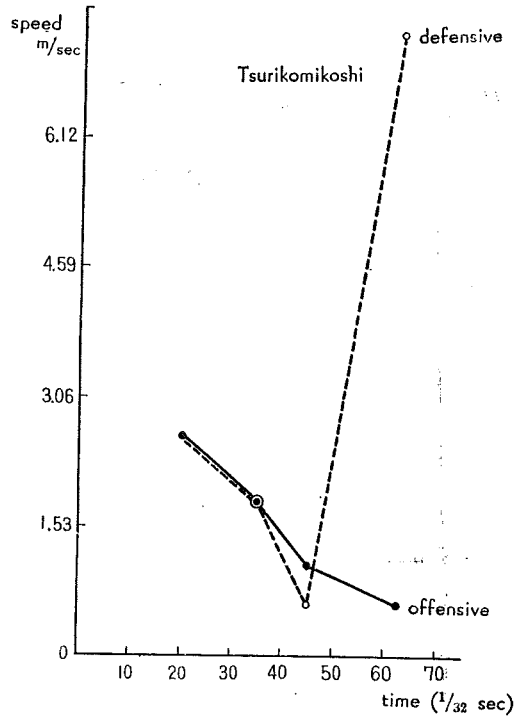


Fig. 29 Tsurikomi-goshi

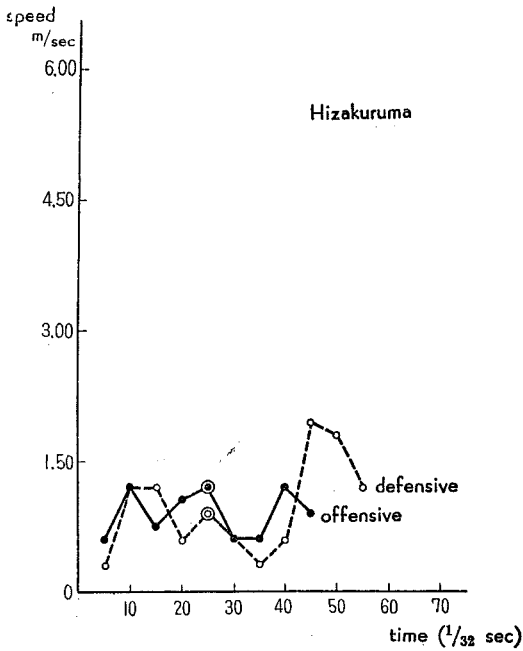


Fig. 30 Hiza-guruma

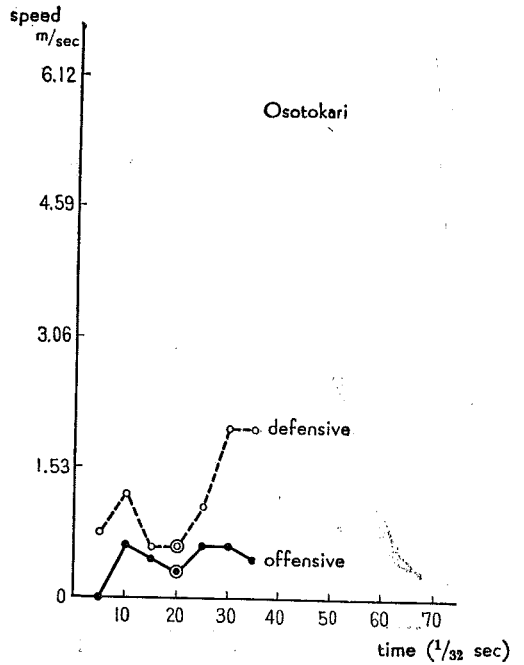


Fig. 31 O-sotogari

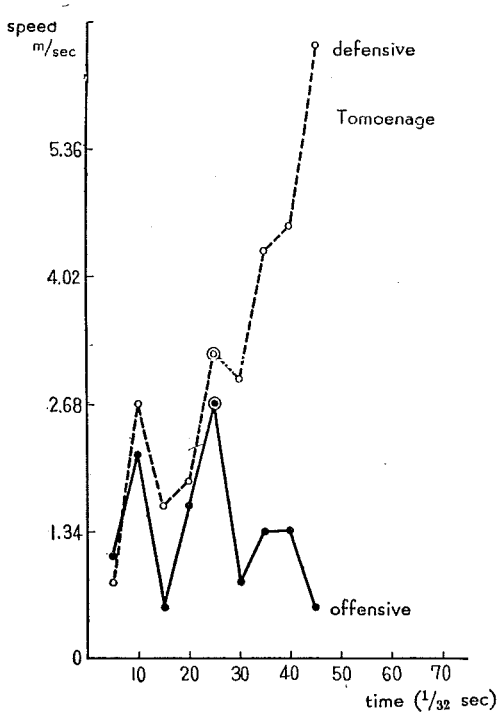


Fig. 32 Tomoe-nage

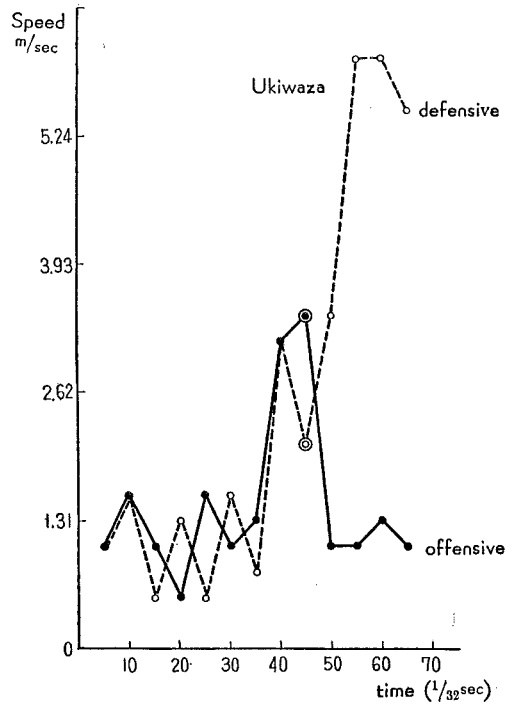


Fig. 33 Uki-waza

mentum of the defensive, and the pull imparted when the offensive drops himself down (Figs. 24, 25).

b) Fig. 24 shows an angle of 60° formed by the relative positions of the centres of gravity of the performers, and suggests that a more adequate position should be taken by the offensive when he drops himself down.

III. The Relation between the Offensive and the Defensive from the Point of View of the Velocity Curves of the Centres of Gravity

The following conclusions may be drawn from a study of the velocity curves of the centres of gravity. a) Although it is natural that the velocity of the offensive is slower than that of the defensive, this difference in their respective velocities become more pronounced after the trick is put on.

Table 1

Technique	Landing vel. m/sec	Landing angle	Angle offensive	Impact kgm/sec
Seoi-nage	3.37	74	30	239~249
Katakuruma	5.18	70	65	315~336
Haraikoshi	4.90	70	0	299~318
Tsurikomikosh	7.00	60	60	445~518
Hizakuruma	1.95	68	0	130~140
Osotokari	1.98	90	0	146~146
Tomoenage	5.89	42	68	291~436
Ukiwaza	6.02	40	60	249~391

b) Contrary to our expectation the velocity of the offensive when the trick is put on is slow and variable. This presumably is because the performers enacted their respective roles with the velocities required during a demonstration. During an actual match

it is expected that the middle part of the curve would be higher.

c) The velocity curve of the defensive was as according to expectation. From this it may be surmised that the whole technique is performed in from one to two seconds, and that the defensive after the trick is put on, is thrown with a high velocity.

The velocity curves of the centres of gravity in the various techniques. (1) Seoi-nage (Ippon Seoi) (Fig. 26). The reason for the drop in the velocity of the defensive at 25/32 sec. is not quite clear, but it may probably be related to the drop in velocity of the offensive at 20/32 sec. when the trick is put on. From the standpoint of the theory of the technique, it leaves room for further consideration on the part of the offensive.

(2) Kata-guruma (Fig. 27). It is to be noted that at the moment the trick is put on, the defensive is carried on the offensive's shoulder with high velocity. The success of this technique depends on whether this part of the trick is properly performed.

(3) Harai-goshi (Fig. 28). The fact that the velocity of the offensive when getting into position for the trick is faster than the defensive's velocity when being unbalanced, shows the complex nature of this technique.

(4) Tsurikomi-goshi (Fig. 29). Note that the velocity gradually diminishes until the trick is put on, when the defensive with high velocity rotates, and is thrown.

(5) Hiza-guruma (Fig. 30). The more active movement of the offensive as compared to that of his opponent prior to the moment the trick is put on may be observed. Only once until 40/32 sec. does the velocity of the defensive exceed that of the offensive, showing the great pains taken by the offensive in getting into the proper position for putting on the trick.

(6) Osoto-gari (Fig. 31). From the figure it may be inferred that the offensive at the centre of the inner circle is cleverly unbalancing the defensive at the outer circle, and shows that their movements are in perfect conformity with the principle of the technique.

(7) Tomoe-nage (Fig. 32). The velocity curve clearly demonstrates that the defensive while gaining velocity is thrown far describing a wide circle. To the offensive the interval between 15/32 sec. and 25/32 sec. is the most strained moment.

(8) Uki-waza (Fig. 33). The high velocity shown in the figure when the offensive drops himself is the distinctive feature of this technique, and behind it lies the force used in throwing the defensive. Another characteristic of this technique is the high velocity with which the defensive is thrown.

IV. The Landing Impact in the Various Techniques

The impact received by the defensive when he lands on the floor, and the angle with which he lands were measured, and are shown in Table 1. The angle with which the defensive lands on the floor is the acutest in the Uki-waza, and the most obtuse in the Osoto-gari. The landing velocities were measured at 5/32 sec. prior to actually hitting the floor, and as a result it was found that in the Hiza-guruma it was the lowest with 1.95 m. p. s., and the highest in the Tsurikomi-goshi registering 7 m. p. s. The landing velocities measured were lower than expected, and were approximately 1/4 of the landing velocity in a skii jump (30 m. p. s.). This we assume is due to the fact that unlike in other free falls, in judo the offensive and the defensive are mutually restraining their movements, and also the defensive puts himself into the proper posture for the fall and breaks the

impact.

The impact of the fall in the various techniques measured in units of the quantity of force are shown in Table 1. The force of impact when the defensive lands differs with the angle with which he hits the floor. It is the largest when the angle (θ) is 90° , and gradually diminishes as the angle becomes more acute. The force of impact may be represented thus :

$$mv \sin \theta$$

where m is the body weight, and v the landing velocity. The figures in Table 1 represent the force of impact calculated with the angle taken at the actual angle with which the defensive hit the floor, and also with the angle corrected to 90° . These figures are nearly identical with the ones obtained during a skii jump when the skier lands smoothly in line with the flight course.

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- (2) W. Knoll: *Der Bewegungsablauf der sportlicher Arbeit* (1936).