QUANTIFYING JUDO PERFORMANCE
AN ATTEMPT TO JUDGE THE EFFECTIVENESS OF THROWING ATTACKS

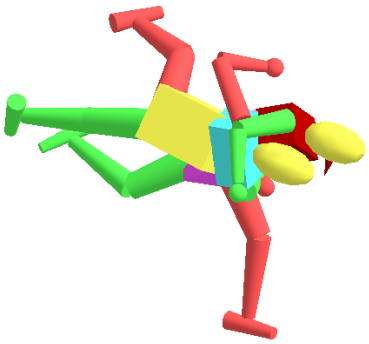
Manfred M. Vieten and Hartmut Riehle
University of Konstanz, Konstanz, Germany

Judo is a combat sport. One way to win is to throw the opponent in a well-performed style. An attempt was made to judge the effectiveness of a throw by analyzing the momentum of the two competitors prior to the throw. We use video kinematography and a simulation system to calculate the momentums. Our method is able to depict the differences between diverse levels of performance quality. Graphics display the differences in the performance skills.

KEY WORDS: judo, harai-goshi, hane-goshi, combat sports, martial arts, kinematics

INTRODUCTION: Jigoro Kano (1860-1938) is the founder of modern judo. He collected the knowledge of the old Japanese jujitsu schools and founded in 1882 the first school of judo. Judo was included in the Olympic Games for the first time at Tokyo in 1964 and held regularly since 1972. Women's Olympic competition began in 1992. Judo is a highly technical sport, which demands skill, strength, and fitness. Competitors (*judoka*) wear a judo suit (*judogi*), a loose-fitting garment of white or blue. The jacket is fastened by a belt, which goes twice round the body and is tied with a square knot. Fighters are judged on throwing technique (*nage-waza*), holding (*osae-komi-waza*), arm locking (*kansetsu-waza*), and choking (*shime-waza*).
In this paper we make an attempt to use momentum to judge the effectiveness of attacks for two different throws the *hane-goshi* (hip spring) and the *harai-goshi* (hip sweep). For details see Jigoro Kano's book "Kodokan Judo" published in 1994 (revised version).

METHODS: Four males and one female participated in this study. Their experience and main anthropometric data are shown in the following table.



Participant	Age	Experience	Weight	Height
1	40	> 20 years (2. Dan)	75 kg	1.75 m
2	23	≈ 8 years (Kyu)	66 kg	1.65 m
3	25	≈ 1.5 years (Kyu)	75 kg	1.79 m
4	24	≈ 1.5 years (Kyu)	83 kg	1.87 m
5	30	≈ 1.5 years (Kyu)	54 kg	1.60 m

Figure 1 - Hane-goshi (depicted using the Hanavan model).

For each subject, 38 anthropometrical measurements were taken. Each participant performed 6 throws (3 *hane-goshis* and 3 *harai-goshis*) with each of the other participants. Altogether 120 throws were filmed. The throws were performed similar to an *uchi-komi* drill (predesigned performance) at a given location on the judo mat (*tatami)*. Movements were filmed using three 50 Hz analog cameras with a shutter speed of 1/1000 sec. A difficult step in the analysis was to select those video sequences in which all the necessary landmarks on the bodies were visible during the whole performance. For reasons of higher accuracy and better recognition of the lower extremities' joints participants wore tight fitting leggings instead of the traditional pants. The traditional jacket however was necessary to allow the judo throws to be performed. Fourteen throws (7 *hane-goshi* and 7 *harai-goshi*) were digitized manually using a Peak 5 system. For each person 16 coordinates (ears, shoulders, elbows, wrists, hips, knees, ankles, and toes) were selected. Therefore, 32 coordinates per frame and 38 anthropometric measurements per athlete were the input for the SDS simulation system. We

used a digital filter that performed the smoothing by damping the FFT spectrum. SDS created the Hanavan model (Hanavan, 1964) see Figure 1 and calculated the inverse dynamics in accordance with the filmed movements. For technical details see Vieten (1999). No additional external forces were measured.

RESULTS AND DISCUSSION: The horizontal momentum of the attacker (*tori*) as well as of the defender (*uke*) in x-direction (direction of movement) and the sum of these two momentums were calculated as functions of time (see figure 2 *hane-goshi* and figure 3 *harai-goshi*).

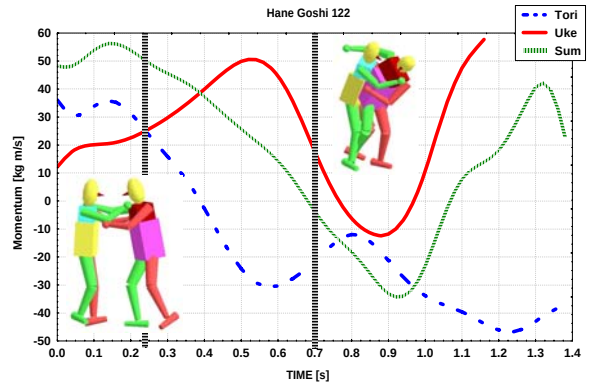


Figure 2 - Momentum of a *Hane-Goshi* Throw, Uke pulling but moving forward.

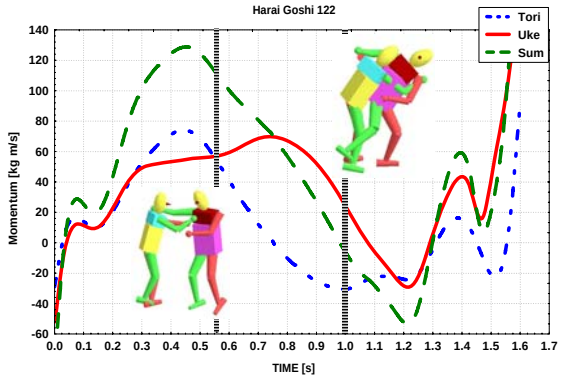


Figure 3 - Momentum of a *Harai-Goshi* Throw, Uke pulling but moving forward.

The left vertical line marks the final sequence before throwing – denoted START. This sequence is either defined by the beginning of the last step or by *uke's* momentum increasing above *tori's* momentum (whatever comes last). The right vertical line marks the time when *uke's* feet loosing contact with the floor – denoted LIFT OFF. We calculated the following five parameters of which the results are shown in figures 4 and 5:

1. The mean difference between *uke's* and *tori's* momentum $\left\langle p_{difference} \right\rangle = \left\langle p_{uke} - p_{tori} \right\rangle$ for the time interval START to LIFT OFF.
2. The maximum of the sum of *uke's* and *tori's* momentum between START and LIFT OFF.
3. The sum of the two momentums at the START.
4. The mean value of the sum of the two momentums between START and LIFT OFF $p_{mean} = \left\langle p_{uke} + p_{tori} \right\rangle$.
5. The momentum $p = p_{uke} + p_{tori}$ at LIFT OFF.

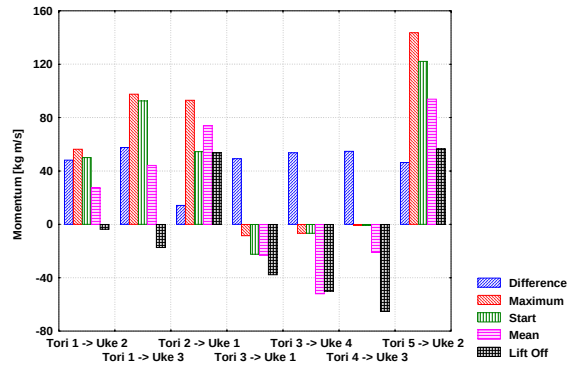


Figure 4 - Momentums of the Hane-Goshi Throws.

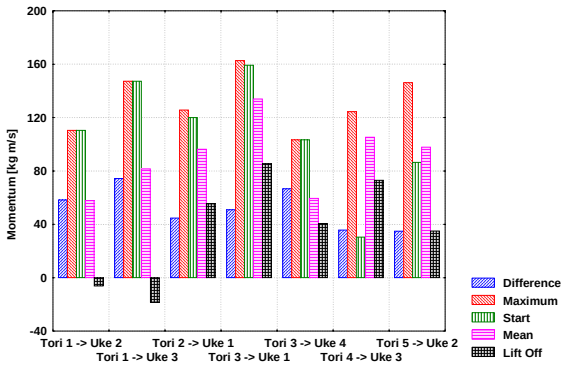


Figure 5 - Momentums of the Harai-Goshi Throws.

For all throws we found a momentum transfer from the attacker (*tori*) to the defender (*uke*) prior to the throw. This momentum is generated by *tori's* action. A *hane-goshi* is a throw where *tori* attacks the opponent's body from the shank up to the shoulder. A pulling action on arm and upper body is combined with a pushing/sweeping of one leg. At the same time *uke's* hip is being uplifted and as a result his or her standing stability is weakened. Therefore, this throw can be performed with a minimal initial momentum. This minimal momentum is necessary to get *uke* off-balance. In a *harai-goshi uke's* body is also attacked from leg up to the shoulder but the uplifting of *uke's* hip is not as prominent. Therefore, the *harai-goshi* needs more initial momentum to be successful. Our data shows the difference of initial momentum between *hane-goshi* and *harai-goshi* for all levels of experience. The initial momentum of the *hane-goshi* differs tremendously in-between the seven throws. In figure 4 the first three throws and the seventh are performed with the *judokas* moving in the direction of the throw. The three other throws are performed from a static position. What is now the signature of a well-performed technique? In case of the *hane-goshi* the signature would be a high momentum transfer prior to the throw; in addition the next three parameters (see figure 4) should contain positive values. The system's minimum momentum can approach small negative values. A *harai-goshi* should be performed with a high momentum transfer (parameter DIFFERENCE in figure 5). MAXIMUM, START and MEAN should display significant higher values as in the case of the *hane-goshi*. The MINIMUM momentum can approach zero or small negative numbers but should not reach substantial negative values.

CONCLUSION: The above-described method allows discriminating diverse levels of performance quality. In addition, with this method we also established a monitoring tool, which quantifies the technical skill of a *judoka* during his or her training process. The method produces definite numbers, which need the interpretation of a coach with a scientific background. The interpretation depends on the situation the two competitors are in. If *uke* pushes *tori* an interpretation will look different compared to a situation in which *uke* pulls. The combination *tori 2* throws *uke 1* is an example for a pushing action for both *hane-goshi* and *harai-goshi*.

The decrease in the system's momentum during the period between START and LIFT OFF (figures 6 and 7) is lower than in the above "pulling" example (figures 2 and 4). Consequently the MEAN system momentum is higher and can elevate above the momentum at the START. The kind of motion, pulling, pushing or neutral is clearly identifiable in the momentum graphs (figures 2, 3, 6, 7, 8 and 9).

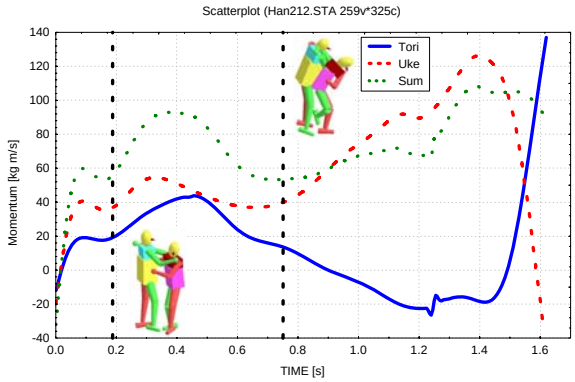


Figure 6 - Momentum of a Hane-Goshi Throw; Uke pushing.

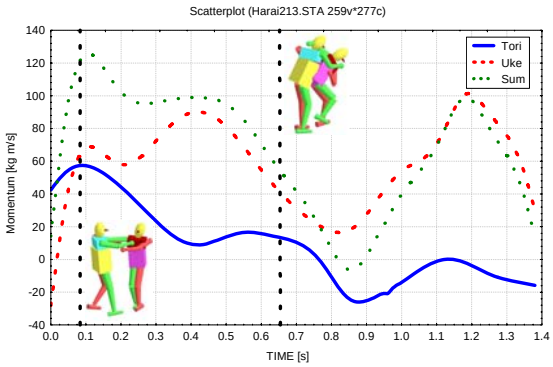


Figure 7 - Momentum of a Harai-Goshi Throw; Uke pushing.

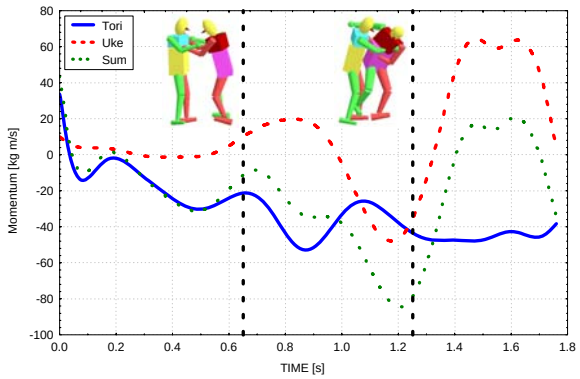


Figure 8 - Momentum of a Hane-Goshi Throw; Uke standing.

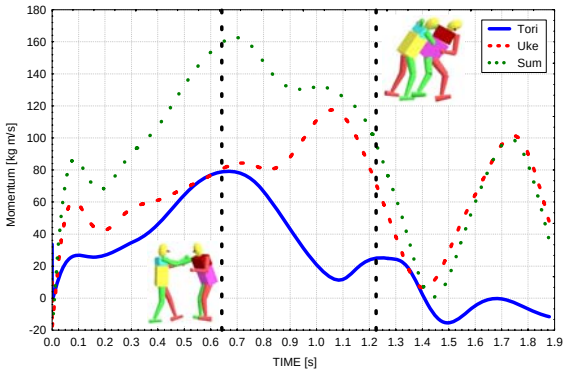


Figure 9 - Momentum of a Harai-Goshi Throw; Uke pulling but moving forward.

The described method does not need external forces as input. Purely kinematical parameters are used. Therefore, a set of cameras and a digitizing system are sufficient to calculate the needed momentums. It is substantial for a tool monitoring the training process to deliver the data right away or at least at the end of a workout. The above-described instrumentation is not capable of delivering the data immediately. However, a modified equipment and a setting of markers (reflective elements on the *judogi* and on the lower extremities) would allow a real time capturing of the marker coordinates.

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Acknowledgements

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