THE BIOMECHANICS OF LOSS OF BALANCE IN OLYMPIC SPORT JUDO, POSSIBILITIES OF MEASUREMENT OF BIOMECHANICAL PARAMETERS

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Throwing techniques represent a substantial part during fighting as their effectiveness highly depends on the development of their technical level. Breaking the opponents balance plays an outstanding role in the known phase of throwing. Therefore the combat athlete must be able to perform explosively and powerfully the attacking moves from beginning to end of a fight. Regarding biomechanics, the parameter of stability and resulting from amount of pull forces necessary to induce the balance losing are quantity of great significance. Since 1978 more than 1000 measurements of national and international world top athletes (taken at central diagnostics of performance in training camp) were analysed. This paper focuses on biomechanical characterization, measurement and the importance of the kuzushi in the forward direction (kuzushi - the first phase of loss of balance).

KEY WORDS: Judo, biomechanical model, pulling force, explosive strength, measurement, movement simulation, elite sport

INTRODUCTION: Throw techniques are a dominant factor in the complex fighting movements of judo. The effective development of throw techniques is an important technical factor and marks a significant part of judo training and performance.

Numerous competition analyses from Olympic Games, World, and European Championships from 1978 to 2004 demonstrate the importance and effective use of throws by the hands, shoulder throws, and foot techniques. In scientific competition statistics are to find the throw techniques most of the times.

In addition, explosiveness and power-endurance capacities have a central importance among the fitness capacities governing judo training and competition. Power-endurance capacities are distinguished by their intensity and near maximal exertion over a certain period (e.g., movement sequences of 10 to 20 seconds), and by the ability to repeat this maximal performance several times during a bout.

Our extended experience in technical and special power training over four Olympiads, has permitted us to develop successful methods for specialized training for elite judo athletes.

The knowledge gained from our experience has culminated in the development of a model of special strength training for judo athletes. An important part of this model has been the ultilization of a simulator that permits movement-specific measurements during training. These measurements have provided diagnostic information that has led to more focused strength and power training.

METHODS: Every judo-specific pulling movement will transfer muscle forces from the attacker to the defender.

The duration, magnitude, and direction of movements determine the momentum transferred to the opponent and the degree of destabilisation conserved by the thrower. From a biomechanical point of view, the degree of stability and the resulting necessary pulling forces required to break the balance of the opponent represent critical determinants of judo success.

Figure 1 illustrates the loss of balance as demonstrated by the principles of torque. This simplified model (the third phase of throw of the attacker and reactive forces of the opponent were not accounted for), shows the tilting of the opponent due to gravity and pulling forces and serves as the foundation for the calculation of the equations of motion.

Anthropometric parameters are included in the moment of inertia ***J***.

The mechanical factors of the balance losing are presented on the following parameters:

pulling force of the attacker in the forward direction

angle of the pulling force

current angular speed of the centre of gravity (CBG) of the opponent

magnitude of the attacking pulling force
CBG-position of the opponent
mass of the opponent
angle positioning of the opponent's CBG to the faltering point
stance - area of the opponent
angle position of the opponent's torso

M_P – pulling torque of thrower	M_G – moment of gravity	M_D – dynamic moment of inertia	G – gravity mg
F_P – pulling force of thrower	K – faltering point	r_S – distance of shoulder to K	r_{CBG} – distance CBG to K
β_S – angle of shoulder during loss of balance	β_{CBG} – angle of CBG during loss of balance	β_F – faltering (tilting) acceleration of body during loss of balance	α – angle between feet
CBG – center of body mass gravity	J – moment of inertia		

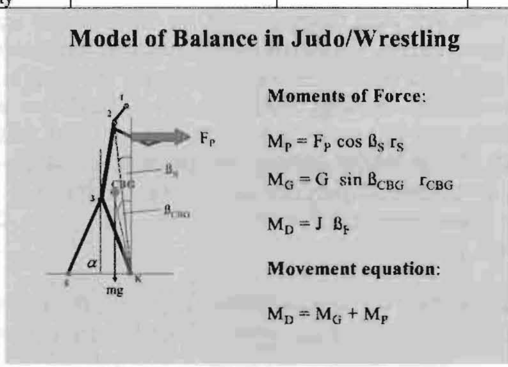


Figure 1 Simplified model of loss of balance as an effect of an outer force in forward direction (CBG-center of body mass gravity).

In summarizing the major influencing parameters, it becomes clear that the attacker largely influences the imbalance of the opponent by the magnitude and direction of the pulling force and thereby causes the imbalance of the opponent.
The remaining parameters are controlled largely by the opponent.
The importance of the pulling force can be demonstrated especially convincingly by computer simulation. For mathematical processing is necessary firstly a measure of pull force. For the acquisition and examination of the special power of throws techniques in Judo dynamometric as well as kinematic measurement procedures were used. By using these measurement procedures, the aim was to quantify biomechanical parameters such as pulling velocity, pulling force, respective time points and force curves.
For obtaining biomechanical parameters, a speed generator (speedo) is used which sends voltage signals proportional to the velocity-time gradient (velocity curve).
This speed generator can be coupled with a retrieval system and mounted on commercially available power or fitness equipment to measure motions largely similar to judo movements.
Figures 2 on left and right side show two possible applications with the further processing occurring at a PC or laptop.
Here (Figure 2, left side) the mass is put into rotation to produce a moment of inertia that simulates the mass of an opponent (weight-class-specific adjustment is possible). A speedo producing velocity proportional voltage signals is used to acquire biomechanical parameters that are processed online and in real-time using a PC for the benefit of parameter feedback. (first possibility: use an analog to digital converter; second possibility: use a pulse width modulation to get voltage for conversion).

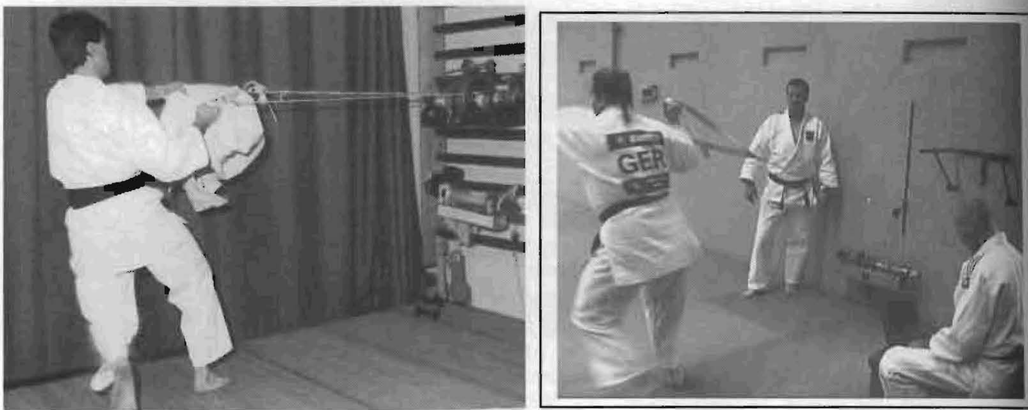


Figure 2 Power machine for pull exercises, type 1left (force transduction of the left and right arm pulling movements by pulling ropes from a rotating mass, resistance was created via a friction-based mechanical strap brake); here: Udo Quellmalz, test during training camp 1992, he was World Champion 1991 and 1995 and he won Olympic Gold 1996 in Atlanta; Power machine, type 2 right (force transduction of pulling movements by pulling ropes attached to a rotational mechanism, here, resistance regulation is velocity dependent); here: Kathrin Beinroth, Vice European Champion 1999, Gold medal winner, EC 2003.

RESULTS AND DISCUSSION: The biomechanical model can be used to show variations in balance control by altering the input parameters and then observe the results of the calculations.
Figure 3 shows the force-time curves and parameter values (e.g. ***Udo Quellmalz,*** 8 weeks prior the Olympic Games 1996 in Atlanta).
The force curves, acquired during practice, represent the foundations for the simulation of the loss of balance and therefore for the description of the faltering movement of the opponent.
The mathematical description of the loss of balance is shown in Figure 1.

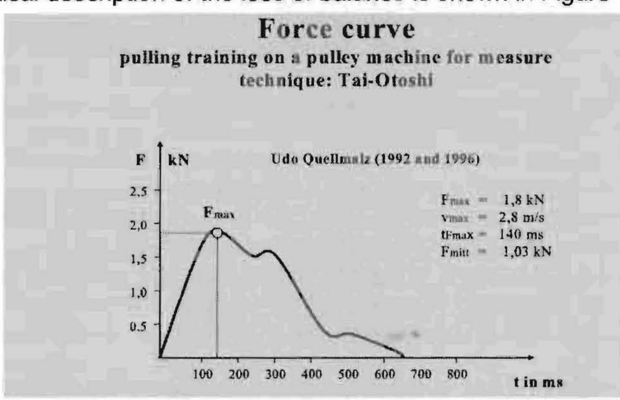
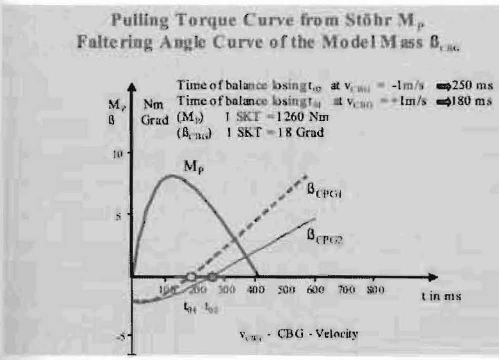


Figure 3 Characteristic force-time curve on an arm pulley machine measurement unit for the Tai-Otoshi technique of Udo Quellmalz (1992 and 1996).

By means of the model simulations, it is possible to investigate the effect of parameter variations (e.g., the change of CBG-movement-velocity of the opponent) on balance behaviour under simulated and reproducible conditions.
The faltering movement of the opponent is regarded as the rotation of the body around the

faltering point ***K*** (toe-hold). For reasons of simplification, the body is regarded as rigid.
As the pulling forces during competitions are directed toward (forward) the upper torso, the moment of torque in the shoulder area is calculated in the following examples.
For example, the heavier weight classes (over 95 kp) illustrate the changes of the faltering angle β_F in relation to the acting (pulling) torque of the thrower M_P. For the example below, pulling forces F_P were obtained from test results obtained in June 1988 (Olympic Games Preparation Phase) from Henry Stöhr (Silver medal winner). Furthermore, the parameters of torso angle, leg separation and angle of head were varied as inputs to the performance model. The simulations shown in Figure 4 involved variations in the velocity of the center of gravity.

model mass of opponent	m_G	136 kg
moment of inertia of opponent	J	205 kgm
faltering shoulder angle	β_S	-24 Grad
faltering angle CBG	β_{CBG}	-33 Grad
distance of CBG to beginning	r_{CBG}	1 m
distance of shoulder to beginning	r_S	1,62 m
angle of legs	α	35 Grad
pulling torque of thrower	M_P	derived from measured force curve



initial velocity of the CBG of the model mass	start of instable body position at:	torque of thrower at t_o:	*CBG velocity at t_o:*
V_{CBG}	t_o	$M_{P(to)}$	$V_{CBG(to)}$
in m/s	in ms	in Nm	in m/s
-3,5	660	0	2,1
-3,0	470	1200	3,5
-2,0	320	1480	5,1
-1,0	250	2600	6,5
0,0	220	5400	7,2
+1,0	180	8300	7,2
+1,5	170	8800	7,3

Figure 4 Left side: Faltering angle change of β_{CBG} of the opponent in relation pulling torque M_P and of the CBG velocity of the opponent (initial velocities V_{CBG} = -1 m/s and +1 m/s);
Table right side: Selected parameters at t_o depending on the initial velocity of the CBG (v_{CBG}) of the model mass–simulation results (top athlete: Henry Stöhr; model mass of opponent m_G = 136 kg; initial faltering angle β_{CBG} = -33 degrees).

By the example the results of *Henry Stöhr* it can be shown that the opponent can be moved out of balance in a matter of a couple of milliseconds despite the opponent's retreat with a CBG-velocity of minus 3 m/s, which means the opponent is moving in a backward direction, (shown as -3 m/s in Figure 4,Table).
The transferred impulse is big enough so that the opponent would fall over after *470 milliseconds*. At this time, a pulling torque applied to the thrower of *1200 Nm* is present (pulling force is F_P*=740 N*). If the opponent was moving forward at a CBG-velocity of 1 m/s (shown as +1m/s), he would fall over after *180 milliseconds* at the same pulling force of thrower.

CONCLUSION: Assuming that a top athlete needs *400 to 800 milliseconds* to react to a pulling force by developing a maximal defensive force, the pulling forces used by the attacker have to be high prior to this.
To achieve a state of imbalance, high pulling forces have to be displayed in a short time.
The judo-specific throwing and fight movements are motorically so complex that neither the training fight the highest special combat exercise similar to fight training nor the technical training with a partner can be completely replaced. The numerous analyses however show that adequate construction of the testing equipment - such as the ones shown here – allow for the training of parts of techniques very similar to the actual movements with an opponent. The basic training methodology is that of coupling an objective, valid, and reliable measuring device to the evaluation of fitness factors like: "specific speed-strength, explosive-strength

and power-endurance". In the broad sense, conclusions about the abilities of strength, speed, and co-ordination for a specific part of a movement can be made.