Three-dimensional analysis of the ju-jitsu competitors' motion during the performance of the ippon-seoi-nage throw

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B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Abstract

Background & study aim: The seoi-nage throw is one of the most often used martial techniques in ju-jitsu and judo. The purpose of this study is the biomechanical analysis of the ippon-seoi-nage throw, based on the shifts, velocity and acceleration values of the centre of mass (CoM) of the competitor executing the technique.

Material & methods: The technique analysis has been based on the research performed on seven Polish representatives in ju-jitsu, aged 25±1.5 years. The attacking competitors' route of the CoM was marked, as well as the durations of motion phases. This was used to calculate the average values of the shift, velocity and acceleration values of the CoM, in a spatial coordinate system.

Results: The highest values of the CoM shifts were noted in the movement towards the opponent and to the ground. The centre of mass movement sideways with respect to the X axis is characterized by small amplitude and is clearly two-way, whereas the CoM movement downwards with respect to Z axis made up about 19% of the average height of the tested competitors. The average maximal values of the CoM resultant velocity of the competitors amounted approximately 2 $m \cdot s^{-1}$, whereas the acceleration amounted about 20 $m \cdot s^{-1}$.

Conclusions: The ippon-seoi-nage technique is a complicated motion outline in which one must combine the elements of the progressive and rotary motion of the body. The effectiveness of the action in the attack is ensured by the fast rotation of the entire body, combined with the gained stable ground position and throwing the opponent off balance. In accordance with the defensive reaction of the opponent, the speed of fitting into the throw and the lowering of the legs are essential for the effective realization of the throw.

Key words: ippon-seoi-nage, centre of mass, velocity, acceleration, 3d analysis

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Ippon-seoi-nage – is one of the Gokyo techniques accepted in Kodokan Judo. This judo technique is classified as a hand throw, Te-waza.

The centre of mass – is the point, where all of the mass of the object is concentrated.

Velocity – is the measurement of the rate and direction of change in the position of an object. In SI units, velocity is measured in meters per second ($m\cdot s^{-1}$).

Acceleration – is the rate of change of velocity over time. In SI units, acceleration is measured in meters per second squared ($m\cdot s^{2}$).

3D motion analysis – is used in several fields of applications: in sports science, clinical gait analysis, physiotherapy and other medical sections. Typical motion analysis measurements acquire kinematic and dynamic data.

INTRODUCTION

The movement activity of ju-jitsu competitors is complex. The competitive fight proceeds in three parts: in the first punches and kicks are allowed to the head, as well as to the torso. In the second throws are mostly used, while in the third grappling techniques dominate (holds, joint locks and chokes). In the case of referee stoppage of the fight, the fight is renewed from the first part in the standing position (IJJF rules, 2000) [1]. In the second part of the fight, the most effective are the forward throws uchi-mata and seoi-nage [2]. An analogy is noticeable between the choice of techniques in ju-jitsu and judo, where the seoi-nage and uchi-mata throws were on top of the list of used techniques in the Olympic Tournament [3].

The scientific analyses of the techniques in judo are much more advanced than in competitive ju-jitsu. In the classification of throws, a number of criteria are used [4]. The results of the research that presented the biomechanical characteristics of the forward throws are known, starting from pulling the opponent during the breaking of the opponent's balance: seoi-nage [5-8], uchi-mata [9, 10], tai-otoshi [11], harai goshi [12] and the backwards throw osoto-gari [13].

The results of testing the masters on the training equipment enable us not only to obtain the biomechanical characteristics of the throws, but also to work on improving the elements of pushing, pulling and sweeping, important for the effective performance of the attack technique [11, 14]. Also interesting are the motion models of the competitors performing the throws in different circumstances, like in the form without resistance nagekomi, with the resistance of the opponent [10] and during the competitive fight Shiai [12].

Because the techniques used in a fight are related with performing the motion in a complex plane, the two-dimensional analysis often does not satisfy the researchers. The accuracy of the experiment requires the usage of the three-dimensional motion analysis [15, 16] to register the motion. It gives many possibilities to analyse the competitor's technique and afterwards to shape it to economize the motion, or to eliminate mistakes. The purpose of this study is the biomechanical analysis of the ippon-seoi-nage throw, based on the shifts, velocity and acceleration values of the centre of mass (CoM) of the competitor performing the technique.

MATERIAL AND METHODS

Experiments were approved by the Bioethics Committee of the Regional Medical Chamber in Krakow, and conformed with the Declaration of Helsinki on the Experimental setup and procedures use of human subjects in research.

The technique analysis has been based on the research performed on seven right-handed competitors, of different weight divisions, Polish representatives in ju-jitsu, medalists of the Polish championship and world championship, aged 25±1.5 yrs. The average body weight of 72.7±6.92 kg, and the height of 1.75±0.053 m. The research of the chosen ju-jitsu techniques were performed at the Institute of University School of Physical Education, Department of Biomechanics in Krakow (Poland). The ippon-seoi-nage throw was analysed, being a special technique of the researched competitors (tokui-waza). Each of the seven competitors executed the technique 3 times. The analysis covered 21 attempts altogether. The competitors were performing the throw in the nagekomi form (the opponent does not defend against the technique). To register the motion; passive (and covered with a reflective material) markers were used; with a radius of 12.5 mm. Elastic markers were used, enabling safe contact of the body with the opponent and the ground. On the skin of the tested person, 39 anthropometric passive markers were placed in precise points, which reflected the position of the characteristic bony points of the head, chest, pelvis, limbs and the joints' axis of the competitor. The motion was recorded with the Vicon system, equipped with five cameras fitted with a set of luminescent diodes, working on the border of the visible light and the infrared with a frequency of 240 Hz. The cameras were arranged on the edges of the three-dimensional measurement surface the size of 10x8x3 m (Fig.1). Vicon system is one of the most accurate tools used to analyse three-dimensional movement techniques, the accuracy and reliability has been repeatedly tested [17].

The emitted light after being reflected from the markers was registered and stored in the database. This enabled the spatial identification of the marker location during the performed motion. The spatial shifts of individual markers (without the perspective distortion) were noted by three coordinates in each frame.

Within the conducted research introduced to the measurement application the anthropometric data, describing the somatic build of the competitors (height, body weight, width/length sizes of the upper and lower limbs and of the pelvis and chest). Due to mathematic modelling a spatial image of the skeleton was obtained, in conjunction with the position of the muscle insertions moving the body segments at the joints.

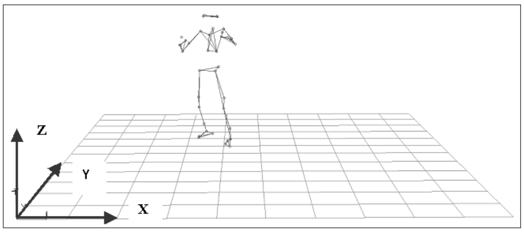


Fig.1. Measurement space and axes orientation of the coordinate system, for registering the throw

The competitors executed the techniques after a warm-up, on a tatami type mat, made out of eight 2x1x0.044 m mattresses (sponge density 240 $kg \cdot m^{-3}$, rice-straw texture covering, anti-sliding bottom, the whole creating a monolith).

The kinematic parameters of the ippon-seoi-nage throw were analysed, distinguishing the motion sequences kuzushi, tsukuri and kake [18]. To simplify the research, kinematic characterization of motion of the competitor's centre of mass was used (CoM) in individual phases of performing the technique. Because CoM is the representation of the entire body, in which the resultant centre of mass that affects the moving body is contained, the description of the CoM motion perfectly resembles the kinematic phenomena of the whole biomechanics area.

On the basis of the technique recording the attacking competitors' route of the CoM was marked, as well as the durations of individual motion phases. This was used to calculate the average values of the shift, velocity and acceleration values of the CoM, with respect to axes X, Y and Z of the spatial coordinate system. The midline plane was composed of the axes system YOZ, the frontal plane XOZ, while the transverse plane YOX (Fig 1).

The resultant V_m speed values of the body's centre of mass, calculated according to the formula:

$$V_r=\sqrt{Vx^2+Vy^2+Vz^2} \qquad (1)$$

where: Vx, Vy, Vz – CoM velocity components calculated in the following X, Y, Z coordinate system (see. Fig.1), Vm – magnitude velocity of CoM.

The resultant acceleration of the attacking competitors' CoM was calculated in an analogical way. The dispersion measure of the results around the average value was presented in the form of twice the value of the standard deviation. In the last stage of the analysis the performing competitors' balance was evaluated in individual phases of the ippon-seoi-nage throw. This enabled the comparison of the parameter values obtained by the tested competitors of a very high technical level.

RESULTS

For the purpose of analysing the ippon-seoi-nage technique, from gaining the grip and taking the initial throwing position until the end phase of the throw, the throw was divided into two sequences (Fig 2). The first was called the preparatory phase, in which the attacking competitor must move forward with a simultaneous rotation of the body and placing the left foot by the inner edge of the opponent's left foot. This causes the unbalancing and a rotating by 180 degrees the thrown opponent until placing both feet on the mat. It was assumed that the kuzushi and tsukuri make up the preparatory phase. After the preparatory phase ensues the proper or application phase (kake), in which the essential element is the lifting of the opponent, commencing his air phase and in the effect his fall (Fig.2).

On Fig.3. is shown the route of the centre of mass with respect to the individual motion axes in the three-dimensional space.

The enclosed diagram shows, that the biggest amplitude of the CoM motion concerns axis Y, directed towards the partner (motion in the midline plane). CoM motion with respect to the other two axes, so to the sideways (X) (frontal plane), and also upwards and downwards (axis Z) presented a much smaller shift change (Fig.3). The first phase is characteristic in the CoM shift towards the opponent with a slight turn to the left side, and with insignificant lowering of the opponent. In the second phase the CoM shift continues towards the opponent, combined with a significant lowering of the opponent and a recurrent motion with respect to axis X. The competitor executes a turn and places himself backwards to the opponent, bends his torso forward lifting the opposing competitor and through the work of the upper and lower limb muscles, as well as the torso, unbalances the opponent, causing his flight towards the mat.

The CoM motion forward is realised due to the move of the trail leg forwards with a rotation with respect

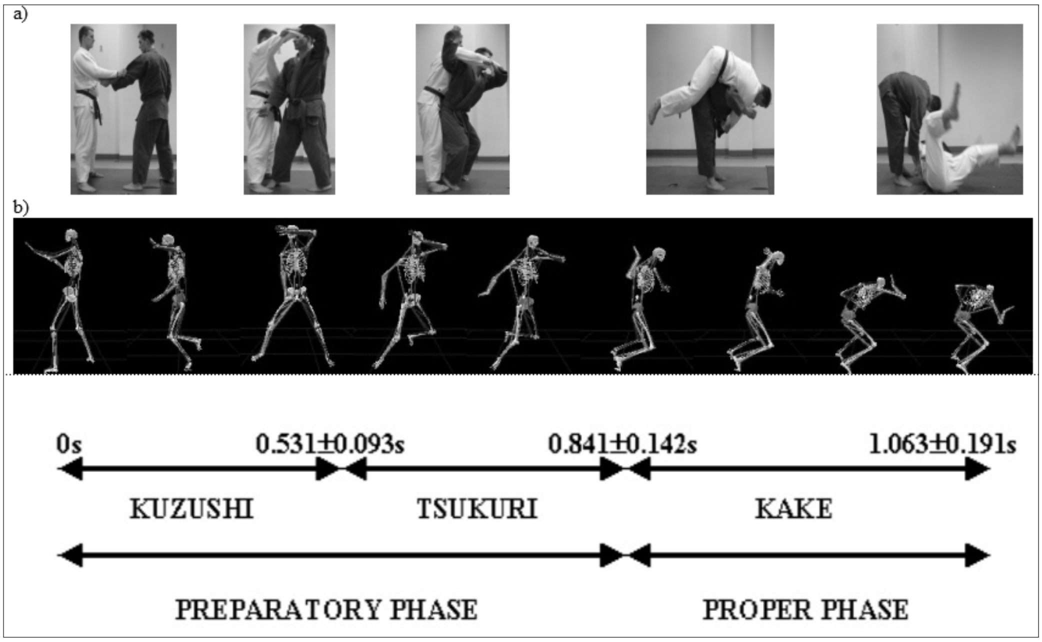
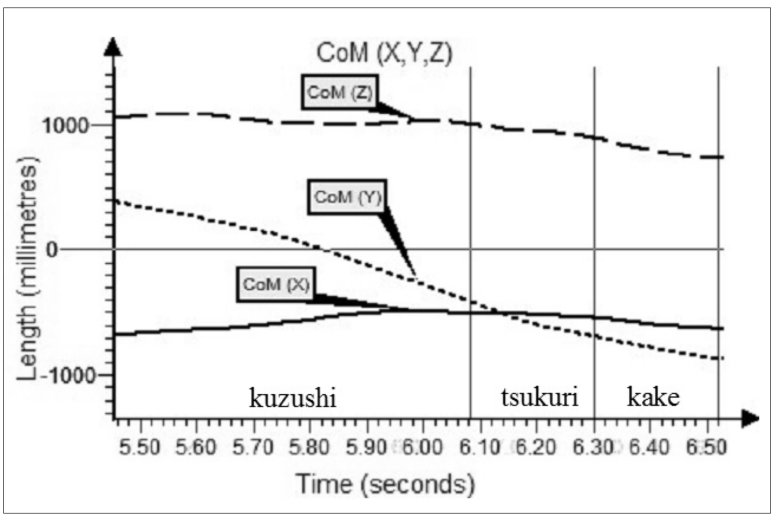


Fig. 2. a) Actual view of the selected phase of the ippon-seoi-nage throw, b) Model diagram used for the analysis of the ippon-seoi-nage throw (side view of the Tori)



Length (millimetres) – shift, Time (seconds) – the time of recording the motion, kuzushi phase – 5.45 s – 6.08 s, tsukuri phase – 6.08 s – 6.30 s, kake phase – 6.30 s – 6.52 s

CoM (X) – solid line, CoM (Y) dotted line, CoM (Z) dashed line

Fig.3. CoM position changes with respect to the individual axes of the coordinate system connected with the measurement area, with marked motion phases (axis X – CoM movement sideways, perpendicular with respect to the axis Y, axis Y – CoM movement forward towards the opponent, Axis Z – CoM movement upwards and downwards)

to the long axis of the body. However, the motion of lowering the CoM is mainly due to a significant bending in the knees and hips, and the bending of the torso forward, with a simultaneous rotation towards the left lower limb.

We can divide the resultant CoM motion into elements with respect to the axes of the coordinate system connected with the three-dimensional space, in which is recorded the competitor's technique (Fig.3.). Fast performance of the preparatory phase requires a coordinated work of the limb and torso muscles, which enables the appropriate velocity and directing the motion of the CoM. The motion in respect to individual axes must by synchronized and must proceed in precisely set conditions, in order to execute the technique in its' full form in as short a time as possible.

Detailed analysis of the CoM movement forward towards axis Y was illustrated on Fig.4. The figure

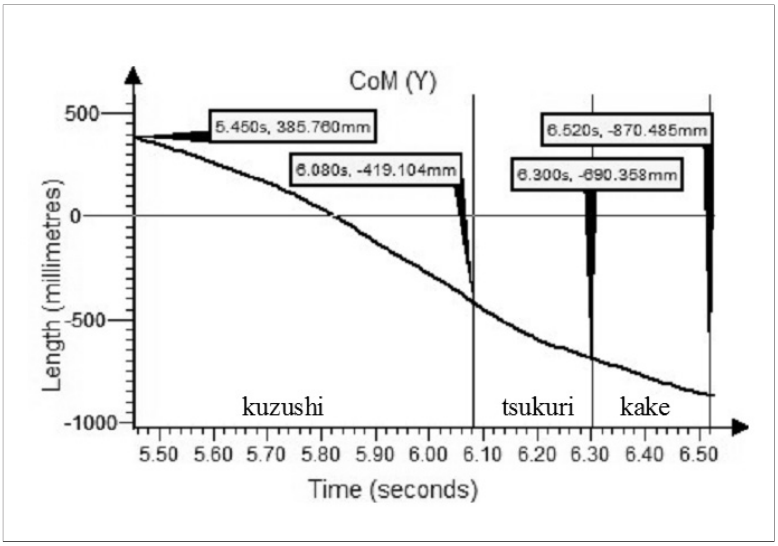


Fig.4. The shift of the competitor's body centre of mass (CoM) forward (with respect to axis Y of the coordinate system) in the ippon-seoi-nage technique

kuzushi and tsukuri – throw preparatory phase

kake – throw application phase

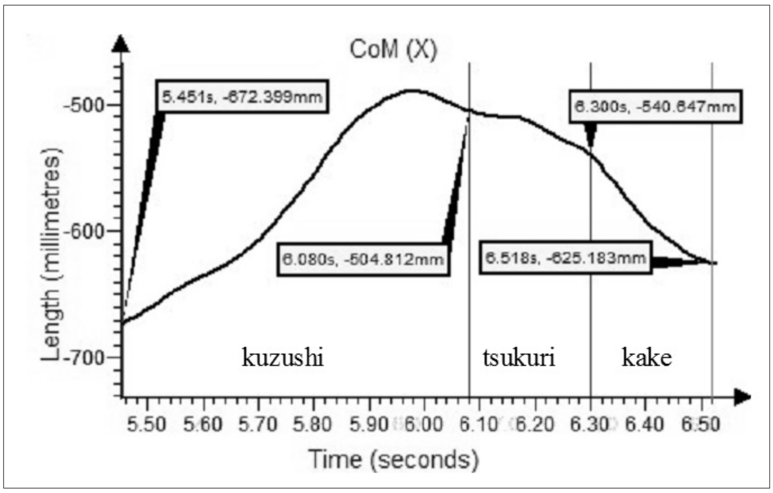


Fig.5. The shift of the competitor's body centre of mass (CoM) sideways (with respect to axis X) in the ippon-seoi-nage technique

kuzushi and tsukuri – throw preparatory phase,

kake – throw application phase

with diagrams presents the shift of the body's centre of mass realised towards the opponent in individual motion phases.

The movement of the centre of mass with respect to axis Y is a unidirectional shift forward. In the preparatory phase of the ippon-seoi-nage technique (kuzushi and tsukuri) a dynamic shift of the body forward ensued, combined with rotation, which effect was the change of the centre of mass position of the competitor in the direction of the intended motion by an average value of 0.805±0.152 m at the time of 0.841±0.142 s. In the application phase of the throw (kake) a further CoM shift ensued towards axis Y, of a value of 0.189±0.016 m at the time of 0.222±0.041 s. The combined average range motion of the centre of mass towards axis Y amounted slightly above 1metre and was the biggest of the analysed CoM shifts with respect to the axes of the coordinate system. The centre of mass movement sideways with respect to axis X (Fig.5.) is characteristic of small amplitude and is clearly bidirectional. The first fragment of the diagram presents the deflection of the CoM left, while the second fragment presents the return to the initial position. The movement direction change happens at the end of the kuzushi phase. The highest shift value happens at the moment of moving the centre of mass forward, combined with the rotation of the pelvis to the left.

The average CoM deflection value in the preparatory phase amounted 0.181±0.040 m (standard error was 0.009 m). In the tsukuri and kake phases we observe the recurrent movement of the body's centre of mass, decreasing it's deflection with respect to axis X.

In the application phase of the throw, the CoM continues to move towards zero on axis X, decreasing its deflection in a such a way, that the difference between the initial and final position of the CoM with respect to axis X amounts only about 0.050±0.006 m (standard error was 0.001m). This shape of the diagram shows that the rotational motion of the body enables the CoM to return near the initial line nominating the direction of the motion.

The motion of the competitor's centre of mass in the direction of the vertical axis (Fig.6.) is unidirectional and is characteristic by its decrease during the whole time span. In the first phase of the motion downwards (preparatory phase) the range of the CoM shift change does not exceed 0.17 m – by average about 0.166±0.028 m (standard error did not exceed the value 0.006 m). The continuing decrease of the centre of mass appears in the application phase of the throw (kake). Its move downwards in this phase with respect to axis Z amounted 0.160±0.031 m, which constitutes for about 96% of the previous range. In the end of the kake phase the centre of mass was at the lowest level with respect to the ground. The average maximal range of the CoM motion with respect to axis Z amounted approximately 0.33 m and constituted approximately 19% of the average height of the tested competitors.

CoM velocity and acceleration analysis

The velocity of 'going under the opponent' is important for the effective performance of the throw, therefore the analysis of this CoM motion variable was conducted in each individual phase of the technique (Fig.7.)

The diagram shows that the CoM obtains the highest velocity absolute values during the motion do the right and downwards. Maximal velocity proportions amount in sequence; with respect to axes Y, Z and X – 1.8:1.1:0.6 $m \cdot s^{-1}$. It is clearly presented, that the velocity components are diverse in the consecutive phases of the throw (Fig.7.). The maximal velocity value of the motion to the right appears during the rotational motion of the body, when the competitor moves closer to the opponent. Subsequently, the next velocity component of the motion forwards gains its maximum. This ensues at the moment of ending the kuzushi phase, in which the velocity towards axis Y clearly decreases, attaining the minimal value at the end of the throw. Such distribution of the velocity components is beneficial for the effective performance of the technique, reflecting the task of each individual motion phase. It is the immediate outcome of the work, made by the muscles of the lower and upper limbs, as well as the torso's, directed at overcoming the external strength (opponent's resistance) and performing the most effective and fast performance of the throw.

Resultant velocity diagram (Fig.8.) is characteristic by its constant increase from the initiation to the end of the kuzushi phase. Resultant velocity attains the highest average value of 1.96±0.22 $m \cdot s^{-1}$ at the moment of finishing this phase of the motion.

kuzushi and tsukuri – throw preparatory phase

kake – throw application phase

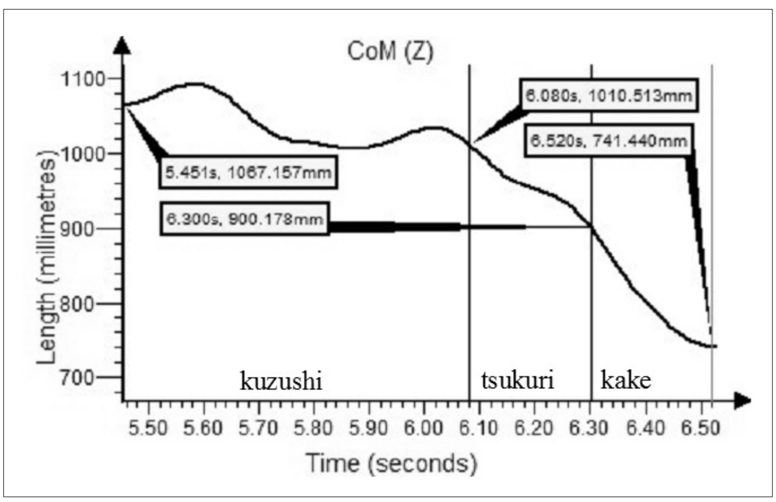
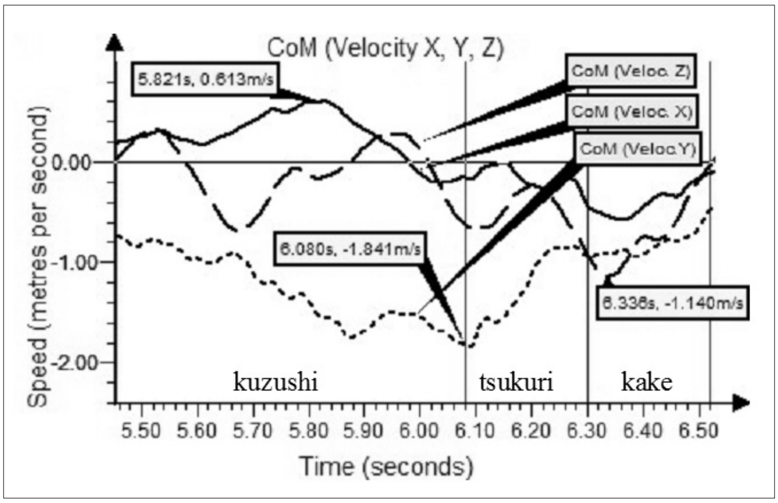


Fig.6. The shift of the competitor's body centre of mass (CoM) with respect to the ground (axis Z) in the ippon-seoi-nage technique



CoM Veloc. (X) solid line,
CoM Velov. (Y) dotted line,
CoM Veloc. (Z) dashed line

Fig. 7. Velocity components of the CoM motion during the performance of the ippon-seoi-nage technique

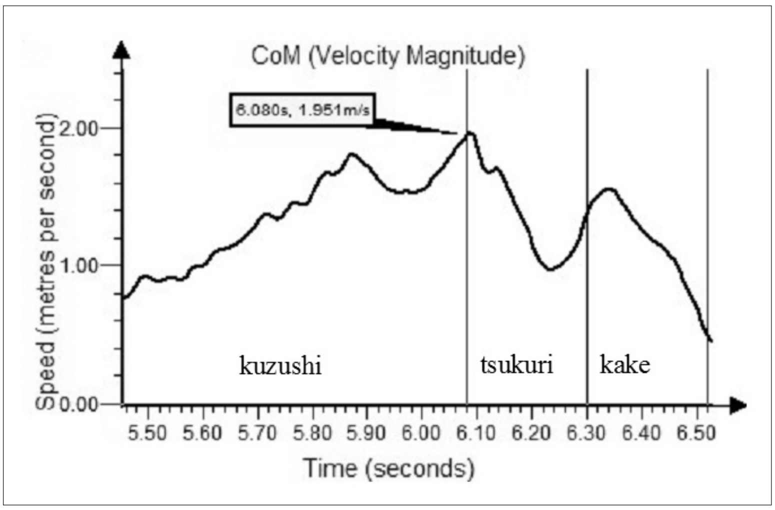


Fig.8. CoM resultant velocity during the performance of the ippon-seoi-nage technique

Standard error value was 0.05 $m \cdot s^{-1.}$ In the tsukuri phase (placing the right foot near the feet of the opponent) we observe a significant decrease of the resultant velocity values, which is mostly connected with the decrease of velocity in the motion forwards. CoM resultant velocity increases in the first part of the kake phase, which can be explained with dynamical lowering of the centre of mass.

Fundamental from the point of view of effectiveness of performing the technique, is the analysis of the centre of mass accelerations. This enables us to determine how competitors control their own bodies by increasing the CoM acceleration with all the affecting internal and external forces.

The diagrams of the CoM component accelerations and the resultant acceleration are illustrated on Fig.9. Diagrams of the variables show that the resultant force working on the punctual weight of the CoM is undergoing constant changes, causing either positive or negative fluctuation of the component accelerations. This shows the constant slowing down and acceleration of the CoM in all three directions of the motion. Another aspect, essential for the acceleration changes, is the resultant weight of the both competitors, which changes dynamically because of the influence of the inertial forces, and the opponent's CoM distance from the CoM of the competitor performing the throw.

The highest acceleration value in the direction of axis X (approximately 11.6 $m \cdot s^{-2}$) obtains the CoM at the start of the kake phase, which is connected with the initiation of a strong rotational motion in its application phase. The component Y has a similar time stress of the acceleration, however its maximal value is considerably higher and amounts about 15.9 $m \cdot s^{-2}$. Acceleration component Z also possesses a few peaks in its range, clearly stressing two of them, appearing at the end of the kuzushi phase and in the beginning of the kake phase (about 10.9 $m \cdot s^{-2}$).

Because of the diverse change tempo of the resultant velocity (Fig.8.) on Fig. 9 we observe the fluctuation of the resultant acceleration possessing an amplitude of about 7 $m \cdot s^{-2}$, which consequent peaks score even higher values. The maximum acceleration of the value of about 17.2±1.8 $m \cdot s^{-2}$ (standard error value was 0.4 $m \cdot s^{-2}$), related with the increasing of the resultant velocity occurs at the end of the kuzushi phase and in the beginning of the kake phase 15.8±2.3 $m \cdot s^{-2}$ (standard error value was 0.5 $m \cdot s^{-2}$). The acceleration analysis shows, that the beginning of the tsukuri phase and the application phase of the throw (kake) is combined with heavy resultant force impulses, which aims for the dynamic performance of the throw. The fluctuation of the component values and the CoM resultant velocity are therefore the effect of the variable resultant force, affecting the combined masses of the competitors, connected with the gripping, unbalancing and pulling the opponent's body forward and downwards.

The conclusive meaning for the obtained values of the resultant acceleration will have the changes of the component velocity values in all directions of the motion.

Body balance during the performance of the ippon-seoi-nage throw

Evaluation of the balance of the attacking competitor was done on the basis of the analysis of the CoM projection's position (bright spot in the pelvis area) on the ground surface (bright spot on the ground) with respect to the competitor's support surface area. The CoM and its projection on the ground is connected by a section presenting the mutual location of the two

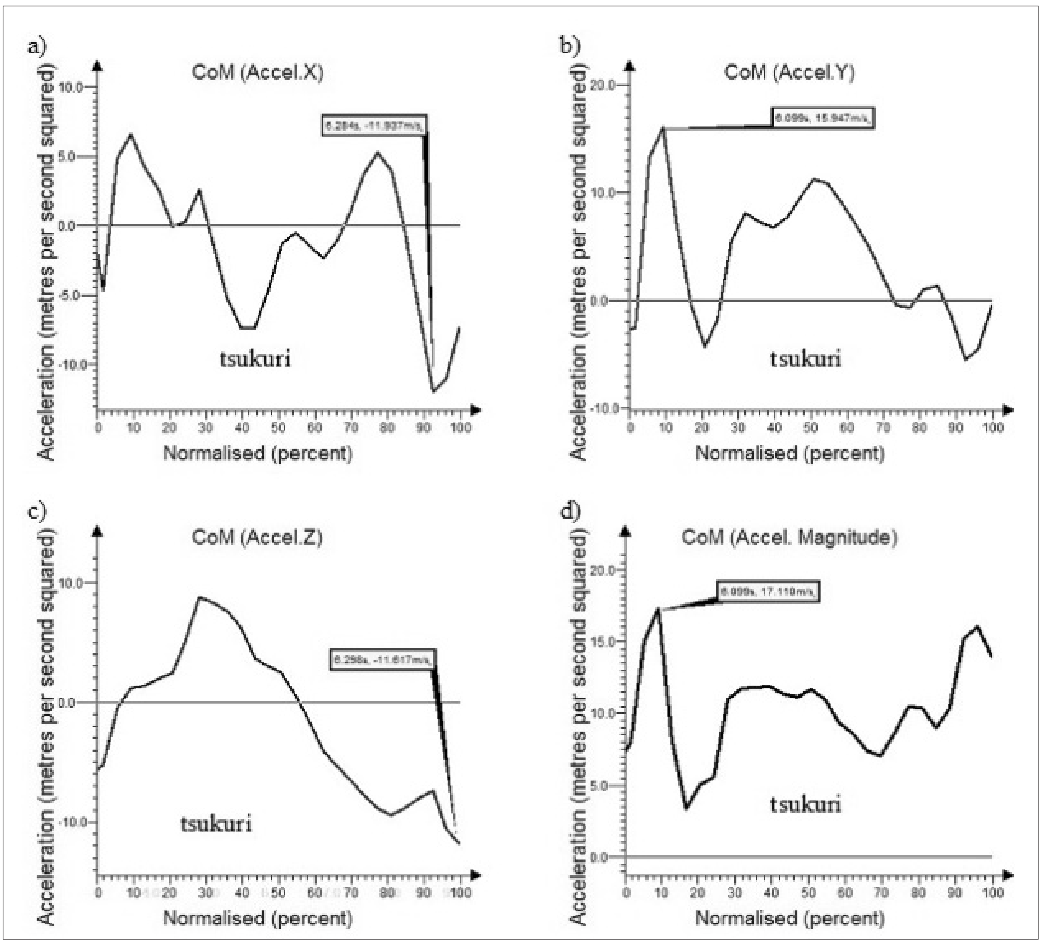


Fig.9. Values of the component velocities X, Y, Z and the CoM resultant acceleration of the motion during the performance of the ippon-seoi-nage technique

spots on the area (Fig.10.). One must notice that the support surface area undergoes significant changes during the performance of the throw. In the phase of only one supporting point it only covers the area the supporting limb's foot touches the ground, while in the phase of two supporting points it is limited to an outline of external edges of the feet (support surface's parallelogram).

In the initial position, the projection of competitor's (performing the ippon-seoi-nage technique) centre of mass falls on the area of the support surface's parallelogram.

The preparatory phase of the throw starts with a fast rotation of the left talocrural joint, opening the way for the right trail limb for a fast 'step towards the opponent' (Fig.11.). Until the moment of the renewed contact of the right foot with the ground, the projection of the centre of mass falls beyond the area of the support surface. The body balance is obtained due to the contact with the opponent and the counterweight that his body creates. During the phase on one support point on the left leg, the competitor is exposed for an effective counterattack of the opponent.

After the regained contact with the ground of the right foot ensues a fast rotation of the whole body, and the left limb follows in the direction of the opponent's left foot, trying to set up a wide, balanced support position at the starting moment of the application throw. The rotational motion of the body is combined with the unbalancing of the opponent and taking his body weight. This phase also demands a lot of physical coordination from the competitors due to the limited support surface and the fast changes of the force. Therefore, the competitors in this phase perform a fast bending of the knees, trying to lower their centre of mass (Fig.12.).

To balance the body weight of the opponent and gain a large leverage during the rotation of the whole mass, the centre of mass must be moved forward and significantly lowered. In order to achieve this, the

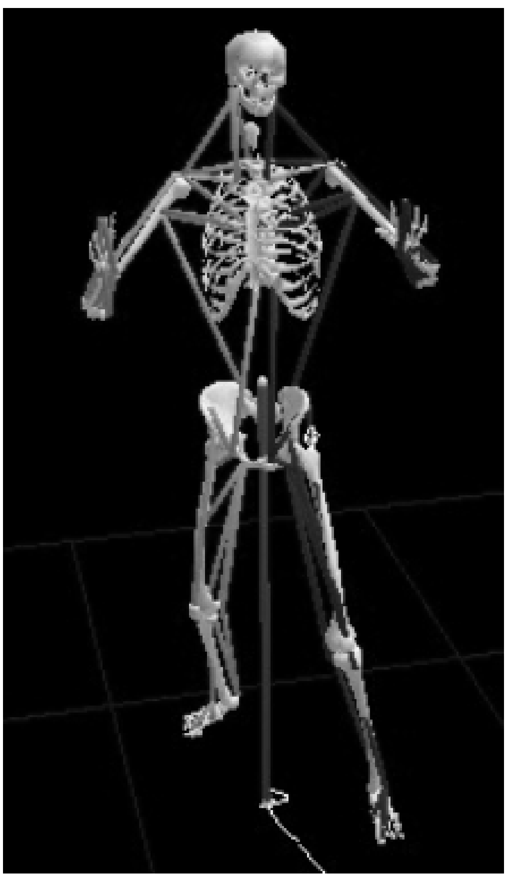


Fig.10. Balance initial position for the ippon-seoi-nage throw (frontal view), white line on the ground – route of the CoM projection on the ground

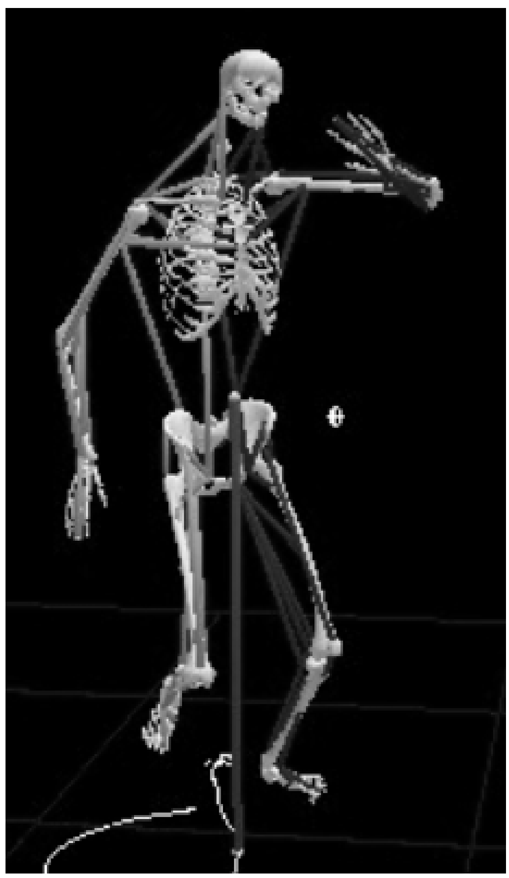


Fig.11. The phase of one support point during the 'going under the opponent' (frontal view)

competitors bend their hips with a simultaneous bending of the torso forward, and the centre of the feet pressure on the ground moves towards the metatarsus.

The projection of the centre of mass on the ground significantly forwards from the support surface's parallelogram (Fig.13.).

Due to this position of the body, based on moving all the masses to the centre of mass, the competitors gain a decrease of the inertial force of the opponent, whose body must be put into a rotation motion. Fast motion of the centre of mass downwards, enables the gaining of the appropriate acceleration of the moving masses. All the elements of the technique are necessary for keeping the balance of the competitor performing the throw.

DISCUSSION

The performed study contributed to the creation of a computer model of the ippon-seoi-nage technique and to measure out the structure time span of the analysed throw. Because of this it was possible to describe the location changes of individual body parts of the tori. (Fig.2.). It's in accordance with the indications of Nakanishi [18], who emphasized the similarities and differences in performing the variations of the seoi-nage throw. In the case of ippon-seoi-nage he paid attention to taking a step with the right leg by the tori and by pulling with the left arm, to unbalance the uke and create the space needed for the attack. This is when the tori puts his bended right arm under the armpit of the uke and grabs from the top the arm of the uke. The tori turns on his right foot and start the rotation of his entire body by 180^o. Simultaneously he lowers his position in comparison to the uke, by bending his legs and his torso. The Uke is pulled by both hands onto the back of the tori and thrown over the shoulder forward and downwards.

Table 1 illustrates the data of the mentioned studies in comparison with the research done by other judo authors.

The average duration of the seoi-nage type throws fluctuated in different studies from 1.0 to 1.14 s. After monitoring the proportions of individual throw phases to the whole time it was claimed that the kuzushi in our own studies and the Blais et al. [7] took half the time of the throw. The tsukuri phase in the study of the ju-jitsu competitors lasted shorter than the French

Fig.12. Balancing the resultant external force generated by the opponent (side view)

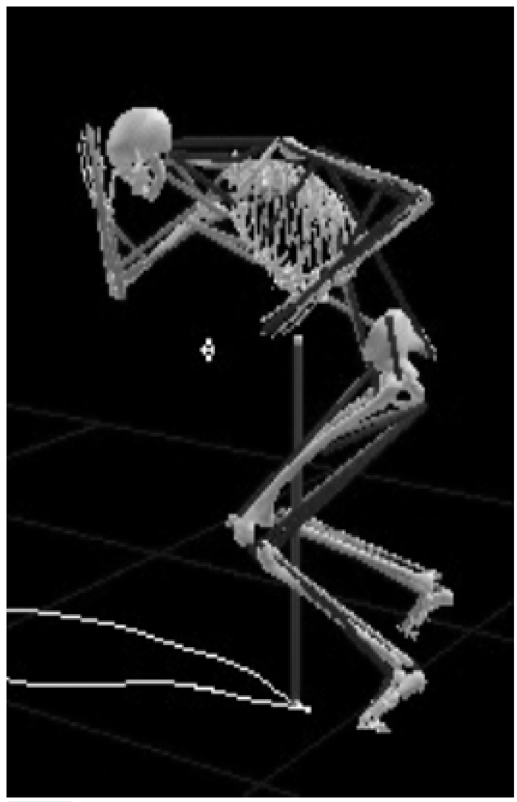


Fig.13. Finishing the ippon-seoi-nage throw

Table 1. Time structure of the seoi-nage type

Author, year	Kuzushi in seconds (%)	Tsukuri in seconds (%)	Kake in seconds (%)	Whole throw in seconds (%)	Throw variation (execution form)
Own study	0.53 (50)	0.31 (29)	0.22 (21)	1.06 (100)	Ippon-seoi-nage (nagekomi)
Blais et al., 2007	0.56 (49)	0.42 (37)	0.16 (14)	1.14 (100)	Morote-seoi-nage (ergometer)
Blais &Trilles, 2004	0.26 (26)	0.46 (46)	0.28 (28)	1.00 (100)	Morote-seoi-nage (nagekomi)

judokas [6, 7]. Other distribution of the motion analysis was used by Imamura et. al., [8]. Treating the tsukuri and kake phases as only one action they registered in the ippon-seoi-nage throw a result of 0.74 s, which was identical to the Blais and Trilles [5].

Taking into consideration the comparable data [5] shown a twice as long kuzushi phase in the ju-jitsu group. However, the ju-jitsu representatives demonstrated the shortest tsukuri phase. One must note that the essence of performing the throw is combining all the phases of the throw, which is characteristic for a masterful performance of the technique. If this is the way we consider the comparable data, the preparatory phase (kuzushi and tsukuri) is the shortest in the studies of Blais and Trilles [5]. The way of performing the throw by judokas was characteristic by a large bending of the lower limbs at the start of the unbalancing of the opponent. Tori knelt down on the mat during the tsukuri and kake, trying to situate the centre of mass of his body below the CoM of the Uke.

The biomechanical analysis of the ippon-seoi-nage throw indicates, that the largest motion amplitude (approximately 1m) applies to the axis (Y) directed towards the opponent. Motion sideways, upwards and downwards was characteristic by a much smaller range. It is directly combined with the first phase of the attack, which purpose is to quickly shift the CoM of the thrower towards the opponent, in order to establish the unbalancing and making him shift the CoM forward beyond the area of balance. In the second phase of the throw the CoM shift is clearly seen, although it is much smaller (about 0.2m) it is continued towards the opponent and combined with lowering his posture. During the motion of pulling the uke forward, when the tori executes a fast turn and situating himself backwards to the opponent – a simultaneous bending in the lower limbs ensues, which moves the pelvis backwards. The result of this is the lack of the CoM turn change from the opponent. The described motion causes the unbalancing of the rival forward and lifting him upwards from the ground. This effect and the air phase of the opponent towards the mat is obtained through a coordinated work of the upper and lower limb muscles, as well as the torso. The most important acceleration values reach the competitors in the moment of beginning the rotational motion backwards (beginning of the tsukuri phase) and at the start of the application phase of the throw (pulling the body forward and downwards). A crucial motion for the dynamics of the throw is the motion of the right shoulder joint, whose task is to balance the weight of the rival. The way of operating the hands in order to gain the grip which his necessary for transferring the energy to the opponent's body, was illustrated by Nakanishi with bare arms [18], (p. 72-73).

Because of the rotational and the progressive motions' kinetic energy generated during the performance of the throw in the shoulder joint, it is import to skilfully balance the motion of pulling the opponent forward and the rotational motion of his body.

Two patterns of reaction during forward kuzushi were observed: (a) the subject placed both feet parallel to each other, (b) the subject stepped forward substantially with the right foot to maintain stability [19]. The defensive reaction of the opponent is often aimed at dodging the attack by moving his right foot forward beyond the right leg of the attacker [18, p. 116-118]. Therefore the speed of initiating the throw is important for the effectiveness of the technique. It is confirmed by the temporal marks of the acceleration stresses, obtained in our own study. The pressure point of the force should be the shoulder, and the work is done my pulling with the left hand, and pushing with the right arm or shoulder. The bending of the lower limbs is also essential, while closing the distance with the opponent. Blais et al. [7] stated that during the morote-seoi-nage the work is done by the lower limbs and the back, not by the upper limbs. This observation should take effect with exercising those body parts with the use of the ergo-metre designed for judo. Our proposed exercises are directed at the improvement of special fitness of healthy competitors, who specialise in the ippon-seoi-nage. These are exercises for practicing the precision of initiating the throw, and the fast legwork in the uchi-komi and nagekomi forms, squats, dead lifts, snatches, bicep exercises. These suggestions are to a large degree, agreeable with the training recommendations of such masters as H. Nakanishi [18, p.119-121] or J. Pedro and Durbin [20, p.170-171].

Before initiating the action, the projection of the centre of mass of the competitor performing the ippon-seoi-nage technique falls on the area of the support surface's parallelogram, which enables the balance of the position (Fig.10.). After initiating the action, the projection of the centre of mass falls beyond the support surface area. Basically, the balance is only guaranteed by the contact with the opponent. Because the centre of mass goes beyond the range of stability, which could end with a fall, but simultaneously this moment is treated as crucial to the effective unbalancing of the opponent. Going 'under the opponent' must be fast (Fig.7.) in order to prevent him from a proper defensive reaction like the previously mentioned step forward. In our own study, the value of this velocity was estimated to be about 1.8 $m \cdot s^{-1}$. A frequent counterattack is also pulling back the attacker (moving the CoM backwards), using the back muscle strength against the arm strength of the attacker. The effectiveness of the throw in the attack can be ensured by the fast rotation of the whole body, combined with gaining contact of the right foot with the ground and taking a wide, stable ground position in addition to unbalancing the opponent. The basis for training seems to be the coordination of a fast bending of the knees and hips with the simultaneous bending of the torso forward, which lowers the CoM. Exercises should focus on training the speed and technique of going 'under the opponent' in the uchi-komi form and with the imitation with rubber expanders. Exercises in the game form should also be present, such as the repetition of the astride jump by the partner and after the turn, going back on all fours between the legs of the opponent to the starting position.

Practical application: crucial for the dynamics of the throw is the motion of the right shoulder joint, whose task is to balance the weight of the opponent, and this is why it is necessary to coordinate both the motion of pulling the opponent forward and the rotational motion of his body. Because the defensive action of the opponent is sometimes directed towards escaping with the right foot forward or pulling back, the speed of initiating the throw is important, as well as lowering the legs, combined with a fast rotation of the whole body and unbalancing the opponent. Basic exercises for improving the special fitness in competitors specialising in the ippon-seoi-nage throw: squats, dead lifts, power snatches, bicep exercises, practicing the speed and technique of initiating the throw.

CONCLUSIONS

Analysing the obtained average parameter values of the centre of mass motion, one must state that, the shift of a largest range in the CoM is in motion in the direction of the opponent and towards the ground.

The average maximal values of the competitors' CoM resultant velocities amounted approximately 2 $m \cdot s^{-1}$, while the resultant accelerations about 20 $m \cdot s^{-2}$.

The ippon-seoi-nage technique is a complicated motion outline in which one must combine the elements of the progressive and rotary motion of the body.

The effectiveness of the action in the attack is ensured by the fast rotation of the entire body, combined with the gained stable ground position and throwing the opponent out off balance.

With the defensive reaction of the opponent focused on escaping with the right leg forward, fast initiation of the throw and lowering the legs is necessary for the effectiveness of the technique

Fulfilling the requirements of the effective realisation of the technique may be reinforced by using in the training process the specialised exercises suggested in the discussion.

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