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Risk assessment in different Judo techniques for children and adolescent athletes

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Abstract

Judo is a combat sport that involves throwing the opponent onto the back. When being thrown, head biomechanics may be related to head injury risk. This study aimed to assess head injury risks associated with four Judo techniques in children and adolescents with different experience levels. Twenty children (<12 years) and twenty adolescents (≥12 years) *judoka* were recruited. Each group was divided in non-expert and expert. Two inertial sensors were fixed on fallers' head and torso. Two backward (*o-soto-gari* and *o-uchi-gari*) and two forward (*ippon-seoi-nage* and *tai-otoshi*) techniques were performed. Peak of linear and angular head acceleration magnitude, impact time duration, neck angle, and Gadd Severity Index (GSI) were assessed. Children did not show differences between techniques or experience levels. In contrast, adolescents showed greater linear acceleration peak in *o-soto-gari* than *tai-otoshi* ($p=0.03$), greater angular acceleration peak in *o-soto-gari* and *o-uchi-gari* than *ippon-seoi-nage* ($p<0.05$), and greater neck flexion in *o-uchi-gari* than *ippon-seoi-nage* ($p=0.004$). Compared to expert adolescents, non-expert adolescents showed greater angular acceleration peak, impact duration, and GSI in *o-soto-gari* ($p<0.05$) and greater neck extension in *o-uchi-gari* ($p=0.02$). Current results pointed out higher risks for adolescents *judoka* while being thrown with backward techniques, especially for non-expert participants. This study highlights the need of training athletes in controlling head and neck during back falls from a young age to become expert *judoka* in adulthood.

Keywords: inertial measurement unit; sports injury prevention; head acceleration; head injury; martial arts.

Introduction

Judo is a martial art originally defined as a physical, mental, and moral pedagogy by the founder Jigoro Kano and it has been recognized as an Olympic sport since Tokyo 1964.[1] Judo has specific effects on bone health[2] and can be practiced safely until older age.[3] Competitive Judo matches involve two contestants, wearing the *judogi* (Judo uniform) and fighting each other using different techniques. These techniques can be classified in throwing techniques (*nage-waza*), in which the thrower keeps the standing position or loses balance in order to project the faller, and grappling technique (*katame-waza*), which includes holding (*osae-komi-waza*), joint (*kansetsu-waza*), and strangulation (*shime-waza*) techniques.[4] A total of sixty-eight different throwing techniques can be exploited by the two contestants, but two of them (*kani-basami* and *kawazu-gake*) have been forbidden in competitions because of their high risk.[4] Among the throwing techniques there are throws in which the thrower (*tori*) projects the faller (*uke*) back, whereas there are throws in which *tori* projects *uke* onto the back with an action for *uke* directed forward.[5] In the present work, throws of the first type were defined backward throwing techniques and throws of the second types were referred as forward throwing techniques according to the movement of the *uke*. Common and efficient backward techniques used in competitions are *o-soto-gari* and *o-uchi-gari*, whereas forward techniques are *ippon-seoi-nage* and *tai-otoshi*.[6,7] *O-soto-gari* (Figure 1, panel A) starts with a great pulling action of *tori* (dark *judogi*) to one side of *uke* (white *judogi*) in order to break the balance by driving him/her on one foot, while *tori* steps forward for getting closer to *uke's* body. Then, *tori* reaps *uke's* leg (unique *uke's* support) from the lateral part driving him/her backwards to the floor. *O-uchi-gari* (Figure 1, panel B) is executed similarly to *o-soto-gari*, but in *o-uchi-gari tori* reaps *uke's* opposite leg from the inside, while hands are used to pull *uke* down. In *ippon-seoi-nage* (Figure 1, panel C), *tori* throws *uke* by using one arm: while pulling *uke* forward, *tori* approaches *uke* by dropping between his/her feet and giving him/her the back. *Tori* uses one arm to grip *uke's* arm and, with a great pull, loads *uke* on the back and throws him/her forward. In *Tai-otoshi* (Figure 1, panel D), *tori* throws *uke* by using two arms: while pulling the uke forward, *tori's* legs are spread to avoid *uke* escaping and to create a lever that increases throwing speed. *Tori's* hands remain on *uke's* sleeve and lapel while pulling the *uke* forward.

**** Figure 1 near here ****

Among the throwing techniques, *o-soto-gari* is considered highly responsible for head injuries.[8] Ishikawa et al.[9] showed that in *o-soto-gari* uke's head undergo higher angular acceleration compared to *ippon-seoi-nage* and *tai-otoshi*. While being thrown on the back, uke may fail to execute *ukemi* and impact head on tatami, fact that may lead to serious injuries such as subdural hematoma, cerebral contusion, and subarachnoid haemorrhage.[8,10] Head injuries have catastrophic consequences; therefore, backward falls kinematics have been recently investigated both in expert and novice *judoka*.[11,12] Linear and angular head accelerations[13,14] and neck angle[11,12] were analysed to assess head and neck injury mechanism. In addition, the Head Injury Criterion has been employed with anthropometric dummies to predict the risk of severe head injuries subsequent to Judo throws with high reliability.[15] The Gadd Severity Index (GSI) has been used in sports such as American Football, Hockey, and Lacrosse to define standards for helmets in order to prevent head injuries.[16,17] However, Head Injury Criterion and GSI have not been applied to Judo athletes while performing throwing techniques in order to evaluate potential risks. To the best knowledge of the authors, no attention has been overall driven to assess potential risks of head injuries in children (<12 years old) during backward falls in Judo.

Biomechanics of *o-soto-gari, o-uchi-gari, ippon-seoi-nage,* and *tai-otoshi* techniques have already been evaluated.[9,18] These techniques have been investigated because of their large usage during matches and the large number of incidence related to them. To assess the biomechanics of throwing techniques, most of the current literature focused on the assessment of the kinematics and dynamics evaluated by means of optoelectronic systems[12,18,19] and force sensors[20] respectively. Optoelectronic systems have high accuracy, frame rate, and spatial and temporal resolution; however, they suffer from limited capture volume, complex markers set-up and cameras calibration, markers occlusion, and artefacts related to their positioning on the *judogi*.[21] Due to athletes' contacts and three-dimensional movements involved in the techniques execution, markers data may be missing. To overcome these limitations, wearable acquisition systems such as inertial sensors have been adopted to determine performance level of elite *judoka* because of their quicker set-up procedures and non-essential line-of-sight of sensors.[22]

Judo has benefit effects on both children and adolescents;[23] however, it has been reported that 90% of head injuries and 58% of neck injuries occur in *judoka* younger than 20 years old.[8] Considering a pool of different sports, it has been shown that adolescents (12-18 years old) have higher injury risk than children (up to 12 years old).[24] Therefore, the main purpose of the current study was to identify the most critical throwing technique among *o-soto-gari*, *o-uchi-gari*, *ippon-seoi-nage*, and *tai-otoshi* for both children and adolescents *judoka*. Head injuries during competitions have also been related to judoka experience level;[8] therefore, the second purpose of the study was to assess risks of expert and non-expert *judoka* while being thrown using the four throwing techniques. In order to assess cranial risks related to different techniques and different experience level, head accelerations, neck angle, impact duration, and GSI have been evaluated during the four throwing techniques in expert children, non-expert children, expert adolescents, and non-expert adolescents. Based on the previous literature,[9] the authors hypothesized to find higher risks for the head in backward techniques compared forward techniques. In addition, it is expected higher risks for less experienced athletes than athletes who have performed this sport for a longer time.[8]

Methods

Participants: A total of forty-two Judo athletes (male=31, female=11) were recruited from the DLF Alessandria Judo team. Participants were divided into children (<12 years old, C) and adolescents (≥12 years old, A).[25,26] Children training 3 times a week for 1 hour each; whereas adolescents training 3 times a week for 2 hours each. During training, both children and adolescents perform technical training and combat simulation; in addition, adolescents perform muscle conditioning. Each group was further divided according to the experience level in terms of years in practising Judo. For the C group, less than three years of experience identified the non-expert children (NE-C), whereas an experience in practising Judo equal to or greater than three years defined the expert children (E-C).[8] For the A group, an experience lower of ten years determined the non-expert adolescents (NE-A) and an experience equal to or greater than ten years identified the expert adolescents (E-A). Participants information are summarized in Table 1. Considering experience, technical skills, and competition outcomes, the best E-C participant (weight=31 kg, height=1.36 m, experience=4 years) and the best E-A participant (weight=81 kg, height=1.77 m, experience=24 years) were identified as *tori* for the C and A groups respectively. Participants and legal guardians in case of minors were informed about the purpose and the protocol of the study and they signed informed consent. The measurements were performed in accordance with the ethical principles of the Declaration of Helsinki[27] and approved by Institutional Expert Committee of the Politecnico di Torino.

**** Table 1 near here ****

Overall design: Tests were carried out on the tatami of the DLF Alessandria Judo and lasted five days. The protocol consisted of two backward projections (*o-soto-gari* and *o-uchi-gari*) and two forward projections (*ippon-seoi-nage* and *tai-otoshi*). The protocol was discussed with the head coach before starting; the throwing techniques used in the current protocol are usually performed by participants during training activities. Each projection was repeated three times before changing technique; the four techniques were performed in a random order for each participant. The protocol lasted around five minutes. To avoid thrower fatigue, a maximum of four *uke* were tested per each day. *Tori* had five minutes rest between two consecutive *uke* because the protocol intensity was substantially lower compared trainings or matches. Both *tori* and *uke* were instructed to perform and received the projections as they usually do in training respectively.

Two inertial sensors (3-Space™ Bluetooth Ultra High-G, Yost Labs, Portsmouth, United States of America) composed of a three-axial accelerometer (range: ±100 g; resolution: 0.049 g) and a three-axial gyroscope (range: ±2000 dps; resolution: 0.061 dps) were used. The two sensors were fixed to the *uke*'s forehead centre and to the *uke*'s middle point of the sternum by using elastic bands (Figure 2). Since the skull can be considered a rigid body, combining the data derived from the two inertial sensors and using a simple biomechanical model (multibody model with two rigid links connected by a hinge joint at C7 level), it is possible to estimate the linear acceleration of any point of the head. To assess head accelerations, in the literature inertial sensors have been also placed in the head centre of gravity of anthropometric dummies,[13,14] on the top of the headgear,[9] or on the mastoid process (behind the ear).[28] Placing inertial sensors on the forehead and on the fourth thoracic vertebra showed very good reliability in evaluating neck angle in sagittal, frontal, and transverse plane (on average ICC>0.88).[29,30] In the current study, athletes hit the back to the mat; therefore, thoracic sensor was fixed on the anterior part of the trunk on *uke's* sternum in correspondence of the fourth thoracic vertebra. Both sensors were aligned while participant was in the anatomical reference position in order to have X axis along the longitudinal direction (upward positive), Y axis along the medio-lateral direction (right positive), and Z along the antero-posterior direction (forward positive). Data were collected with a sampling frequency of 800 Hz using CoolTerm application, which allows storing raw data of acceleration and angular velocity on a personal computer.[31]

**** Figure 2 near here ****

Data analysis: The duration of a throwing technique is around 0.8-0.9 s[32]; therefore, for the analysis one second of raw signal centered in the peak of head linear acceleration magnitude was selected. Raw data of linear acceleration and angular velocity were filtered with a zero-lag 4th order Butterworth passband filter with cut-off frequencies of 1 Hz and 50 Hz; filter type, order, and cut-off frequencies were experimentally defined to reduce noise and avoid drift. The magnitude of the linear accelerations of the head was calculated by using the three acceleration components measured by the forehead sensor. The head angular acceleration magnitude was calculated using the derivative of the angular velocity along the three axes of the sensor fixed on the forehead. The magnitude of the linear and angular acceleration have been previously investigated to assess Judo falls.[9,13,14,28] The peak of the head linear acceleration magnitude (a_p) and the peak of the head angular acceleration magnitude ($\dot{\omega}_p$) were then evaluated. The impact duration (t_i) was calculated as the interval of time in which the head linear acceleration was higher than a threshold. The acceleration threshold was chosen, according to the literature, equal to 10 g for all participants because this value was identified as non-injurious during non-impact events for children[33] and adolescents.[34] The neck angle was calculated as the integral of the difference between the head and thoracic angular velocity along the medio-lateral direction (Y axis).

$$neck\ angle = \int_0^D (\omega_{head}(t) - \omega_{sternum}(t))\, dt$$

where:

D = impact duration

$\omega(t)$ = angular velocity along the medio-lateral direction

Neck angle has been previously investigated to assess Judo falls.[11,12] Only the flexion/extension movements of neck were considered because values of neck rotations and abduction/adduction movements during the projections were negligible and because the flexions and extensions are the most common impact direction that causes severe head traumas.[8] The neck angle was considered positive during neck extension and negative in neck flexion. The maximum neck extension angle (θ_e) and the maximum neck flexion angle (θ_f) were identified respectively as the maximum and the minimum values of neck angle curve. During a projection the most critical instant is when head undergoes high acceleration peak,[35] hence the neck angle was also evaluated in correspondence of a_p (θ_p). Finally, for all the participants who showed a_p greater than the threshold the GSI was calculated as it is defined in Gadd et al.[17]

$$GSI = \int_0^D a(t)^{2.5}\, dt$$

where:

D = impact duration

$a(t)$ = head acceleration module

In automotive or sports impacts, the most commonly adopted criterion is Head Injury Criterion, which has been already used to assess Judo throws using an anthropomorphic test device.[15] This index is calculated over a period of time around 15 ms, requiring high sample frequencies (range 8-20 kHz) to obtain reliable data.[36] The sample frequency in the current study was 800 Hz; therefore, the GSI was used because it compensated for lower temporal resolution acquisitions considering the t_i.[37]

For each variable, the average value among the three repetitions was calculated for statistical analysis. Data were single-blind processed by a researcher using MatLab custom script (MatLab R2018b, The MathWorks Inc., Natick, Massachusetts, United States of America).

Statistical Analysis: Statistical significance level was set at $\alpha=0.05$ for all conducted analyses. Statistical analysis was conducted using MatLab (MatLab R2018b, The MathWorks, Inc., Natick, Massachusetts, United States of America). Data distribution was assessed using Kolmogorov-Smirnov test. Data did not show normal distribution ($p<0.01$), therefore non-parametric statistics was applied in the analysis. For the head biomechanics parameters (ap, $\dot{\omega}_p$, θ_e, θ_f, θ_p), the intrasubject variability among the three executed repetitions for both C and A groups was evaluated using coefficient of variation.

Differences between the four techniques for neck angle variables (θ_e, θ_f, θ_p) and for $\dot{\omega}_p$ were assessed using a Friedman test, evaluated separately for C and A groups. The effect size was calculated as Kendall's W test (W)[38] and Tukey-Kramer post hoc test was used when necessary. Concerning the a_p, a Chi-square test was used to assess the relationship between the four techniques and the number of athletes who exceeded the threshold in C and A groups. The effect size was calculated as Cramer's V (V)[38] and a post-hoc analysis was used to identify the techniques that showed a disproportion when necessary. The Friedman test was also used for a_p, t_i, and GSI, for C and A groups separately, including only the athletes with a_p higher than the threshold in all the four techniques. The effect size was calculated as Kendall's W test (W)[38] and Tukey-Kramer post-hoc was used when necessary.

A Mann-Whitney test was used for each technique to assess differences between NE-C and E-C and between NE-A and E-A. For statistical differences, the effect size was calculated as η^2.[38]

Results

Coefficient of variation of head biomechanics parameters for both C and A groups is reported in Table 2. Overall, the C group showed higher intrasubject variability compared to A group for head biomechanics parameters, with the only exception of the θ_p in *o-soto-gari* technique.

**** Table 2 near here ****

Comparing the four techniques, no differences were found in C group for the $\dot{\omega}_p$ ($\chi^2(3)$=6.1, *p*=0.11, W=0.10), θ_e ($\chi^2(3)$=1.5, *p*=0.69, W=0.02), θ_f ($\chi^2(3)$=4.2, *p*=0.24, W=0.07), and θ_p ($\chi^2(3)$=1.3, *p*=0.73, W=0.02) (Figure 3). In C group, no associations were found between the techniques and the number of athletes who exceeded the a_p threshold ($\chi^2(3)$=1.7, *p*=0.62, V=0.15) (Table 3). In addition, the results showed that the highest percentage of C athletes who overcome the a_p threshold was 35% in *o-soto-gari* (Table 3). Due to the very low number of C with suitable values of a_p, the Friedman test was not performed for C group.

**** Table 3 near here ****

Concerning the A group, statistical differences were found between techniques for the $\dot{\omega}_p$ ($\chi^2(3)$=17.9, *p*=0.0005, W=0.30), θ_e ($\chi^2(3)$=11.0, *p*=0.01, W=0.18), θ_f ($\chi^2(3)$=15.6, *p*=0.001, W=0.26), and θ_p ($\chi^2(3)$=14.3, *p*=0.003, W=0.24) (Figure 3). *Ippon-seoi-nage* had lower $\dot{\omega}_p$ compared to *o-soto-gari* (*p*=0.0003), *o-uchi-gari* (*p*=0.04), and *tai-otoshi* (*p*=0.01). Concerning the neck angle, lower values of θ_e were found in *ippon-seoi-nage* than *tai-otoshi* (*p*=0.006); whereas θ_f was greater in *o-uchi-gari* than *o-soto-gari* (*p*=0.003) and *ippon-seoi-*

nage (p=0.004). Lower θ_p was found in *o-uchi-gari* than *o-soto-gari* (p=0.009) and *tai-otoshi* (p=0.01).

**** Figure 3 near here ****

In A group, a significant association between the techniques and the number of athletes who exceeded the a_p threshold was found ($\chi^2(3)$=11.5, p=0.009, V=0.39) (Table 3). The post-hoc analysis identified a disproportion between athletes who exceeded and who did not exceed the a_p threshold in *ippon-seoi-nage* compared to the other techniques ($\chi^2(3)$=11.6, p=0.0006). Indeed, in *o-soto-gari*, *o-uchi-gari*, and *tai-otoshi* at least 80% of the athletes exceeded the a_p threshold; whereas in *ippon-seoi-nage* the percentage of athletes who exceeded and who did not exceed the a_p threshold was equal (Table 3). The comparison of the four techniques including the athletes who exceeded the a_p threshold showed statistical differences ($\chi^2(3)$=12.0, p=0.007, W=0.50). In particular, greater a_p in *o-soto-gari* was found compared to *tai-otoshi* (p=0.03). In contrast, t_i ($\chi^2(3)$=2.9, p=0.42, W=0.12) and GSI ($\chi^2(3)$=7.7, p=0.06, W=0.32) did not showed statistical differences between techniques.

Overall, the comparison between NE and E in the C group did not showed statistical differences for the $\dot{\omega}_p$, θ_e, θ_f, and θ_p, and in none of the four techniques (Figure 4). In particular, in *o-soto-gari* $\dot{\omega}_p$ (U=102.0, p=0.88, η^2=0.001), θ_e (U=107.5, p=0.88, η^2=0.001), θ_f (U=91.0, p=0.31, η^2=0.05), and θ_p (U=96.5, p=0.55, η^2=0.02), in *o-uchi-gari* $\dot{\omega}_p$ (U=113, p=0.57, η^2=0.02), θ_e (U=98.0, p=0.62, η^2=0.01), θ_f (U=103.5, p=0.94, η^2=0.0003), and θ_p (U=97.5, p=0.60, η^2=0.01), in *ippon-seoi-nage* $\dot{\omega}_p$ (U=119, p=0.31, η^2=0.05), θ_e (U=110.0, p=0.73, η^2=0.006), θ_f (U=88.0, p=0.21, η^2=0.08), and θ_p (U=101.5, p=0.82, η^2=0.002), and in *tai-otoshi* $\dot{\omega}_p$ (U=117, p=0.38, η^2=0.04), θ_e (U=105.0, p=1.0, η^2=0), θ_f (U=82.5, p=0.09, η^2=0.14), and θ_p (U=106.0, p=0.97, η^2=0.0001). The comparison between NE and E was not performed for a_p, t_i, and GSI due to the very low number of participants in C group with acceptable values of a_p. For A group, NE-A showed greater $\dot{\omega}_p$ (U=72.0, p=0.01, η^2=0.30), longer t_i (U=53.5, p=0.05, η^2=0.21), and greater GSI (U=54.0, p=0.05, η^2=0.21) than E-A in *o-soto-gari* technique (Figure 4). Significantly greater GSI was also found for NE-A compared to E-A in *ippon-seoi-nage* (U=23, p=0.04, η^2=0.41). NE-A showed also greater θ_e than E-A in *o-uchi-gari* (U=74, p=0.02, η^2=0.27); whereas a_p, θ_f and θ_p did not show differences between NE-A and E-A for none of the four techniques (Figure 4). In particular, in *o-soto-gari* a_p (U=59.5, p=0.15, η^2=0.11), θ_f, (U=104.5, p=1.0, η^2=0) and θ_p (U=117.0, p=0.38, η^2=0.04), in *o-uchi-gari* a_p (U=54.0, p=0.15, η^2=0.13), θ_f (U=120.0, p=0.27, η^2=0.06), and θ_p (U=92.0, p=0.34, η^2=0.04), in *ippon-seoi-nage* a_p (U=25.0, p=0.11, η^2=0.26), θ_f (U=112.0, p=0.62, η^2=0.01), and θ_p (U=102.0, p=0.85, η^2=0.002), and in *tai-otoshi* a_p (U=59.0, p=0.14, η^2=0.12), θ_f (U=122.0, p=0.21, η^2=0.08), and θ_p (U=99.5, p=0.70, η^2=0.007).

**** Figure 4 near here ****

Discussion

Four Judo throwing techniques (*o-soto-gari*, *o-uchi-gari*, *ippon-seoi-nage*, and *tai-otoshi*) were analysed to evaluate potential risks for children and adolescents *uke* related to forward and backward throwing techniques and to different experience levels. In the C group, most participants did not overcome a_p threshold in the four techniques; whereas in A group, *ippon-seoi-nage* was the technique that showed the highest number of participants who did not reach the a_p threshold. Comparing the techniques, no differences were pointed in the C group; whereas A group showed higher a_p, higher $\dot{\omega}_p$, and greater θ_f in backward than forward techniques. Comparing NE and E, C group did not show differences; whereas the main findings for the A group were lower $\dot{\omega}_p$, shorter t_i, and smaller GSI for E-A than NE-A.

Regarding the techniques comparison, the fact that very high number of C participants did not reach the acceleration threshold in all the four techniques is an important finding, which may suggest that children react similarly to both backward and forward techniques while being projected without identifying particular risks related to none of the four techniques. This finding is in line with a previous study that concludes that Judo is a safety sport for children by analysing parameters like the forces exchanged and contact area between judoka and tatami and the energy absorbed by tatami.[39] The absence of differences between techniques in C group could be due to the intrasubject variability and to the force exerted by the thrower during the projections. It is possible that due to the very low age, children might use sub-maximal expression of force (especially for the very young children). If this occurred, it would be possible that characteristic features of each technique would not be as highlighted as in A group; however, in order to confirm this suggestion, the exchanged force between *tori* and *uke* should be assessed. For A group, the fact that most athletes overcome the acceleration threshold in both backward techniques, but only in one of the two forward techniques is an important outcome that suggests higher risks for backward than forward falls. Higher a_p and $\dot{\omega}_p$, and greater θ_f found in backward techniques, especially in *o-soto-gari*, aligned the current results with previous findings, supporting intrinsic risks related to the rear falls compared to forward throws.[9] In the current study, lower a_p and $\dot{\omega}_p$ results were found compared to Murayama et al.[13,40] and Hitosugi et al.[14] However, in previous studies[13,14,40] an anthropometric test device was used, and since it was a passive dummy, there was always an impact of the head with the tatami. In contrast, in the current study, participants react to prevent the head to impact on the tatami (despite sometimes it occurred). Current assessed $\dot{\omega}_p$ was overall higher than the values found by Ishikawa et al.;[9] however, in the previous study[9] projections involving head collisions were discarded. Overall, $\dot{\omega}_p$ found in current study and $\dot{\omega}_p$ found by Ishikawa et al.[9] have the same pattern among techniques, with the highest value for *o-soto-gari*, followed by *ouchi-gari* and *tai-otoshi* (that show similar values), and finally *ippon-seoi-nage* (with the lowest $\dot{\omega}_p$). Although t_i did not showed differences between techniques, results of t_i found in current study are in line with the 20 ms reported by Histosugi et al.[14] for *o-soto-gari* and *ouchi-gari*. To understand concussion in sport, Hoshizaki et al.[41] present relationships between a_p and t_i and between $\dot{\omega}_p$ and t_i using values reconstructed from the literature and comparing them with the Wayne State Concussion Tollerance Curve and Van Lierde Tolerance curve[42] respectively. The comparison of current a_p, $\dot{\omega}_p$, t_i results with the graphs reported by Hoshizaki et al.[41] reveals that the throws performed in the current study are overall in the area of non-injurious sport collisions. Although not significant, overall greater values of GSI were found for backward than forward techniques suggesting that this index may be suitable also for Judo sport. In the current study GSI reached values clearly lower than 1000, value that has been identified as responsible for causing severe complication in 50% of cases.[43]

Concerning the comparison between NE and E in C group, in line with the literature[8] three years were used to distinguish between experienced and non-experienced *judoka*. The absence of significant differences between NE-C and E-C could be due to the fact that the two groups are partially overlapped in terms of age (Table 1) and could be also due to the intrasubject variability (Table 2). However, to confirm this suggestion a statistical analysis considering single and mixed effects of age and experience level of participants should be performed. Regarding the comparison between NE-A and E-A, the lack of difference in a_p is in line with results of Koshida et al.[44] that report no differences in linear acceleration during backward falls between experienced and novice judoka. The absence of differences in θ_f between experienced and novice judoka while being thrown with *o-soto-gari* is in line with findings of Koshida et al.[11] They found also lower neck extension moment in experienced compared to novice judoka and suggest that neck extension moment reflect judoka skill level; thereby, this parameter should be considered in further analysis when experience level is investigated.[11] Greater θ_e was found for NE-A compared to E-A in *ouchi-gari*, indicating that novice should be accurately being taught important components such as controlling the neck in order to prevent head risks.[44] Finally, greater $\dot{\omega}_p$, longer t_i, and greater GSI for NE-A compared to E-A in *o-soto-gari* pointed out that being thrown with *o-soto-gari* may be more challenging that being thrown with other techniques, as suggested by Koshida et al.[12] This aspect should be considered when novice *judoka* are trained. Current results point out other two aspects. Firstly, ten years of experience seems to be suitable for finding differences in the management of impact acceleration in the A group. Secondly, differences in performance based on experience levels appear more in adolescents athletes than in children.[45] Specific exercises to improve management of forces and technical executions in backward techniques are highly recommended in training of NE-A.

Two possible limitations can be identified in the current study. In order to reduce the intragroup variability, in this study one *tori* was recruited to throw all the *uke* of the A group and one *tori* for the C group. However, this did not consider differences related to anthropometry (weight and height) and/or gender, which may differently contribute to projections. Secondly, the number of participants recruited per each group was defined a priori based on previous studies that show differences between techniques and between experience levels.[9,11,12,18] The lack of power analysis to define the sample size could be a limitation of the present study; therefore, future researches should provide it.

Concerning future research, it could be worth evaluating differences between techniques and between experience levels in terms of accelerations, neck angle, and impact duration in a more real situation, such as during combat. In current study, the participants were asked to execute throws as they usually do in training and combat; however, gestures executed in remain more controlled.

Conclusion

The present study assessed the risk of head injuries related to four Judo techniques counting for differences related to *uke's* age and experience levels using two inertial sensors. Showing no differences between techniques or experience levels for children, this study indicates that children undergo less risk of incurring in head traumas when practicing Judo. Identifying differences in characteristic parameters (accelerations, neck angle, impact duration) in adolescents, this study reveal that adolescents have higher risk when being thrown backward than forward. In particular, *o-soto-gari* pointing out more severe impacts for non-expert adolescents than expert adolescents, suggests their higher risk of incurring in head injuries. Current findings confirmed the necessity of mastering falls, especially in backward direction, since the young age in order to avoid traumatic episodes in adulthood.

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Table 1. Participants information reported as mean ± standard deviation for each group.

	NE-C	E-C	NE-A	E-A
Height (m)	1.26 ± 0.01	1.37 ± 0.08	1.63 ± 0.11	1.73 ± 0.05
Weight (kg)	25.9 ± 8.4	32.1 ± 9.6	56.4 ± 13.1	66.1 ± 6.0
Age (years)	7 ± 2	8 ± 1	16 ± 7	21 ± 5
Experience (years)	1.5 ± 0.5	3.4 ± 0.7	6.7 ± 2.4	14.1 ± 5.4
Training frequency	3 times a week (1 hours each)		3 times a week (2 hours each)	
Training typology	technical training and combat simulation		technical training, combat simulation, muscle conditioning	

Note: NE-C: non-expert children, E-C: expert children, NE-A: non-expert adolescents, E-A: expert adolescents.

Table 2. Coefficient of variation results to assess intrasubject variability for head biomechanics parameters for children (C) and adolescents (A) groups in the four techniques (*o-soto-gari*, *o-uchi-gari*, *ippon-seoi-nage*, *tai-otoshi*).

	O-soto-gari		*O-uchi-gari*		*Ippon-seoi-nage*		*Tai-otoshi*	
Head biomechanics parameters	C	A	C	A	C	A	C	A
a_p	41%	41%	37%	38%	36%	31%	39%	34%
$\dot{\omega}_p$	61%	42%	54%	34%	53%	39%	59%	45%
θ_e	73%	61%	89%	59%	98%	56%	80%	35%
θ_f	83%	62%	92%	42%	69%	66%	66%	45%
θ_p	27%	155%	39%	27%	273%	18%	41%	10%

Notes: head biomechanics parameters are peak of the head linear acceleration magnitude (ap), peak of the head angular acceleration magnitude ($\dot{\omega}_p$), maximum neck extension angle (θ_e), maximum neck flexion angle (θ_f), neck angle in correspondence of a_p (θ_p).

Table 3. Percentage of association between techniques and judoka who exceeded the linear acceleration (a_p) threshold. For children (C) and adolescents (A) groups the number of athletes who exceeded and did not exceed the a_p threshold is reported for the four techniques as number, percentage between the four techniques, and percentage within the test. The Likelihood Ratio Chi-square (*p* = p value, V = Cramer's V effect size) is reported in the last column.

			Techniques				
			T1	T2	T3	T4	Chi-square
C	$a_p \geq 10$ g	Number	7	4	4	6	1.7 (*p*=0.62, V=0.15)
		% between techniques	33.3%	19.0%	19.0%	28.7%	
		% within test	35.0%	20.0%	20.0%	30.0%	
	$a_p < 10$ g	Number	13	16	16	14	
		% between techniques	22.0%	27.1%	27.1%	23.8%	
		% within test	65.0%	80.0%	80.0%	70.0%	
A	$a_p \geq 10$ g	Number	18	16	10	18	11.5 (*p*=0.009, V=0.39)
		% between techniques	29.0%	25.8%	16.1%	29.0%	
		% within test	90.0%	80.0%	50.0%	90.0%	
	$a_p < 10$ g	Number	2	4	10	2	
		% between techniques	11.1%	22.2%	55.6%	11.1%	
		% within test	10.0%	20.0%	50.0%	10.0%	

Note: T1 = *o-soto-gari*, T2 = *o-uchi-gari*, T3 = *ippon-seoi-nage*, T4 = *tai-otoshi*

Figure 1. Sequence of movements in four throwing techniques: (A) *o-soto-gari*, (B) *o-uchi-gari*, (C) *ippon-seoi-nage*, (D) *tai-otoshi*. In dark *judogi* the thrower (*tori*) and in white *judogi* the faller (*uke*).

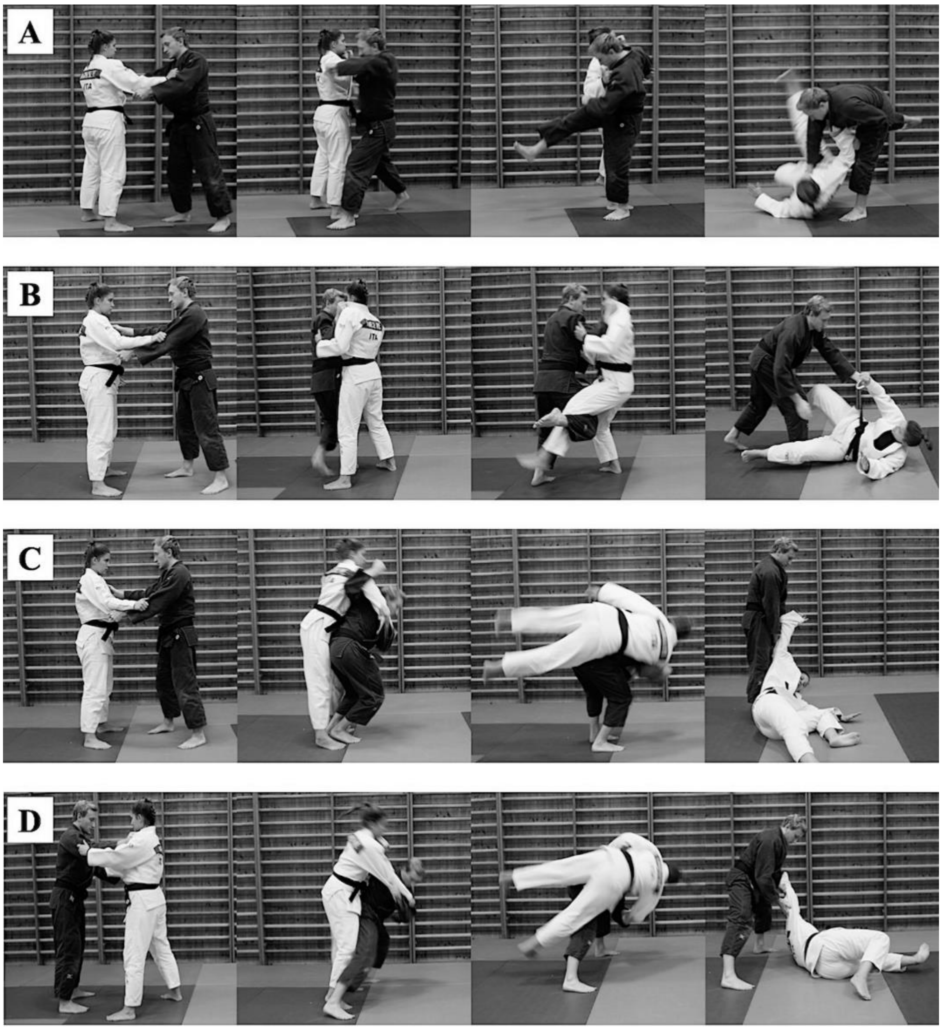

Figure 2. Inertial sensors positioning on *uke's* body: one sensor on the forehead centre and one on the sternum.

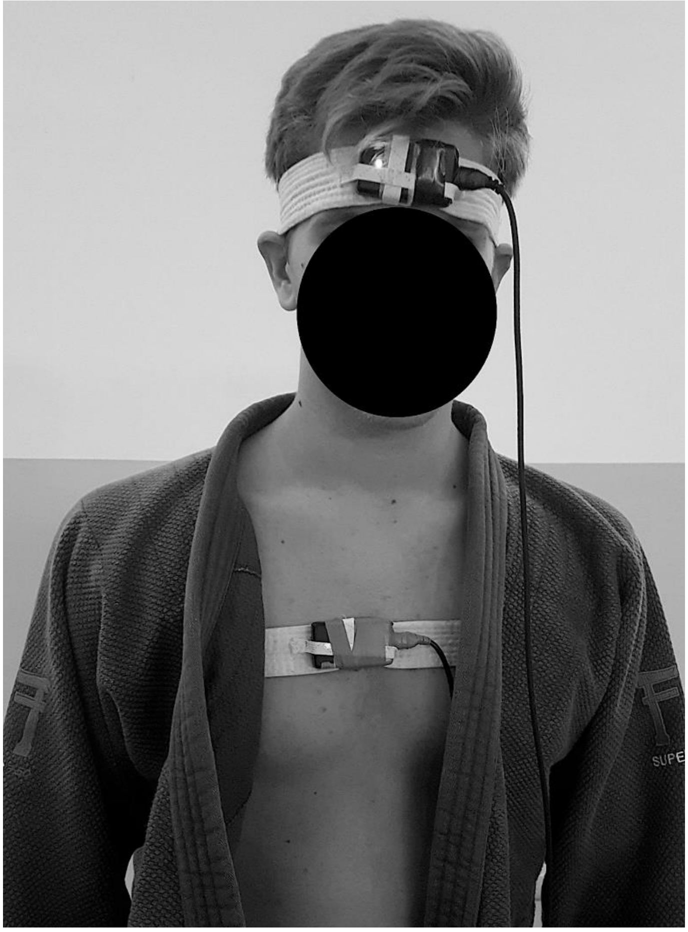

Figure 3. Mean and standard deviation of calculated variables for the four tested techniques (T1 = *o-soto-gari*, T2 = *o-uchi-gari*, T3 = *ippon-seoi-nage*, T4 = *tai-otoshi*) in children and adolescents. ∗ p<0.05, ∗∗ p<0.01, ∗∗∗ p<0.001.

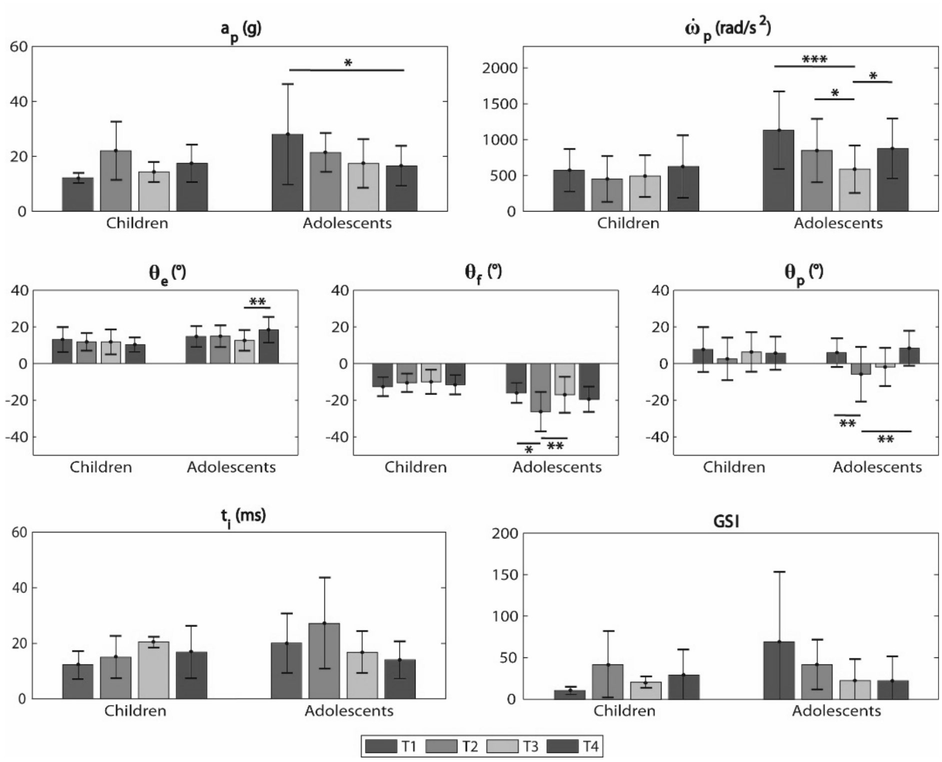

Figure 4. Mean and standard deviation of calculated variables for each sub-group: non-expert children (NE-C), expert children (E-C), non-expert adolescents (NE-A), and expert adolescents (E-A), in the four techniques (T1 = *o-soto-gari*, T2 = *o-uchi-gari*, T3 = *ippon-seoi-nage*, T4 = *tai-otoshi*). $*$ p<0.05, $**$ p<0.01.