

Article

Video-Biomechanical Analysis of the Shoulder Kinematics of Impact from Sode-Tsurikomi-Goshi and Tsurikomi-Goshi Judo Throws in Elite Adult Judoka

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Abstract: Background: The aim of this study was to calculate and compare the peak acceleration and peak negative velocity of uke's shoulder during the course of two judo throwing techniques, Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG). Methods: This study recruited male adult elite judo players with a mean age 26.5 of (SD = ±8.916), a minimum black belt ranking, and no injuries in the past six months. Participants were selected from the Aris Judo Club, Thessaloniki, Greece, ensuring high-level technique for safe and reliable outcomes. Informed consent was obtained. A Huawei 5T with a 48-megapixel camera was used to record the throws. Kinovea (version 0.8.15) software was used for two-dimensional motion analysis of shoulder displacement during throws and IBM SPSS Statistics (version 25.0, Armonk, NY, USA) with Microsoft Excel were used for the statistical analysis of the data. Results: The peak acceleration of uke's shoulder during STG was lower than in the case of TG, but the statistical test did not confirm this difference ($p = 0.1$). The mean peak negative velocity of uke's shoulder in TG was higher compared to STG, and this difference was statistically significant ($p = 0.04$). The test–retest reliability of STG throws was good (ICC = 0.74), and for TG throws, it was moderate (ICC = 0.60). The effect size was large for negative velocity in TG (d Cohen = 1.12) and moderate for acceleration in STG (d Cohen = 0.43). The individual test did not show a statistically significant difference between STG and TG ($p = 0.2$). Conclusions: A statistically significant difference in peak negative velocity in TG compared to STG would reveal that uke is thrown quicker by tori. Further research on impact forces to determine the effective mass of uke's shoulder is advised.

Keywords: injury; judo; velocity; acceleration; impact force



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1. Introduction

Judo, introduced by Kano Jigoro in 1864, became an Olympic sport in 1964 and is now practiced by over 20 million people worldwide. The sport was created as a moral pedagogy to teach discipline, respect, and physical courage to judokas (e.g., fighters or

opponents). There are three basic categories of techniques (waza), including throwing (nage-waza), gripping (katame-waza) and striking (ate-waza) practices. Combining ground and standing fighting, judokas attempt to either throw their opponent to the ground or pin them on their back on the floor. The terminologies for the thrower and the faller are tori and uke, respectively.

The risk of musculoskeletal injuries in judo is higher compared to other sports, such as soccer and wrestling, due to the high-impact nature of throws [1,2]. Recent studies report an 11–12% average injury risk during the latest Olympic Games, mainly affecting uke when landing after being thrown by tori [3]. Beyond the injury risk data from the Olympic Games, other studies have indicated that shoulder injuries in judo are prevalent during both training and national competitions. This is attributed to the repetitive nature of throwing techniques and high-impact landings, particularly among less experienced athletes. Due to the nature of techniques, uke mainly lands on the shoulder, meaning this area is frequently injured, and acromioclavicular dislocation, rotator cuff tendinopathies, and clavicle fractures are common injury findings [4]. To help readers better understand the significance and practical implications of this study, a detailed description of common shoulder injuries in judo is warranted. These include rotator cuff injuries, acromioclavicular dislocations, and clavicle fractures. Such injuries often result from repetitive strain or improper landing techniques, with contributing factors including excessive joint rotation, high impact forces, and inadequate breakfall skills. Therefore, judo's popularity in combination with the critical risk of injury requires further research to ensure judokas' safety [4].

The biomechanical analysis of judo techniques that involve shoulder movement of high risk of injury can be helpful to develop preventative methods [5,6]. Although the importance of judo throwing techniques in competition is widely recognized, there is a lack of a detailed review of the current research status, especially concerning the biomechanics of shoulder motion. In particular, research on changes in shoulder force, acceleration, and speed during judo throws remains underexplored. Addressing these gaps highlights the innovation and importance of the present study. Two throws that strongly engage the shoulder are Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG), and to be initiated, tori and uke should be facing each other [7]. STG is performed by tori taking a grip on both uke's gi (uniform) sleeves, holding one high above uke's head, lifting and loading them on tori's back to finally throw uke to the ground (Figure 1).



Figure 1. Standing Sode-Tsurikomi-Goshi.

An additional variation of STG involves tori executing the throw from a kneeling position, which can alter the dynamics of the throw (Figure 2).

In TG, tori grips uke's collar with one hand and a sleeve with the other, pulling upwards while pivoting and lowering their body to position uke on their back, ready for the throw. This technique emphasizes a strong collar grip, which provides greater control over uke's upper body compared to STG (Figure 3).



Figure 2. Knee Sode-Tsurikomi-Goshi.



Figure 3. Tsurikomi Goshi.

While lifting uke, tori turns to face the same direction as their opponent when landing. The throw can be performed with tori either standing or kneeling. In TG, similarly, tori takes a grip on uke's collar and is pulling uke upwards continuously while lowering their body and pivot on their left leg until uke is on tori's back at the level of the waist, before throwing them forward. A step-by-step summary of both nage-waza is shown below.

The kinematic analysis of other judo throws has been able to identify biomechanical elements that are correlated with a certain injury [5,8]. For instance, in o-soto-gari (large outer reap) as compared to o-uchi-gari (large inner reap), the vertical velocity at which uke's head decelerates is associated with a greater risk of head injury and is reduced by increasing the body surface exposed to the collision with the tatami (judo-mat) [9]. Therefore, submitting STG and TG to a similar testing procedure could allow experts to recommend further suggestions that may lessen the risk of injury.

Greater impact forces are associated with increased incidence of injury risk and the values of acceleration and velocity can be used to determine them. Such estimations have been vital in the understanding of prevention of severe injuries, such as traumatic encephalopathies and concussions; therefore, it is important to investigate them further [5,10].

To our knowledge, there is no available research investigating the analysis of shoulder kinesiology and the impact forces that are applied during these throws [11–13].

In this study, we aim to conduct a video analysis of the Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG) judo throwing techniques. The primary objective is to track the displacement of uke's shoulder and determine and compare the following parameters among elite adult judokas: (a) the peak acceleration and (b) the peak negative velocity at the moment of impact on the ground. For the detailed achievement of the objective, the following research questions have been formulated: 1. What is the peak acceleration of uke's shoulder during the Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG) judo throwing techniques? 2. What is the peak velocity of uke's shoulder during the Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG) judo throwing techniques? 3. Is there a significant difference in the peak acceleration and peak velocity of uke's shoulder between the STG and TG judo throwing techniques? 4. The research hypothesis is that at least one of the two variables will have greater or lesser value in one of the two throws over the other.

2. Materials and Methods

2.1. Recruitment and Participants

This study was conducted in December 2020. Six national team members (elite) competing at an international level (A–F) were recruited for the study. The athletes' mean (range) values and SD = standard deviation of their age, height, weight, and BMI was 26.5 years (18–42), SD = 8.916; 181.22 m (175–195), SD = 7.09, 89.33 kg (73–109), SD = 14.26; and 27.15 kg/m² (22.5–34.4), SD = 3.931, respectively. Body weight was measured using a Tanita BC-601 (Tanita, Tokyo, Japan), whereas body height was measured using a SECA 2017 body height meter (Seca, Hamburg, Germany).

Seven pairs were formed, with the first participant mentioned being tori. A total of 12 throws were performed (6STG, 6TG) and recorded at 30 Hz. One pair (D–E) performed an additional group of 3 throws of STG, where tori executed the technique in kneeling position.

Sode-Tsurikomi-Goshi pairs were A–B, B–D, D–C, E–C, C–E, and F–B.

Tsurikomi-Goshi pairs were A–B, B–D, D–B, E–C, C–E, and F–B.

A minimum sample size of six was calculated with reference to another study that video-analyzed judo throws [6]. This was made using G*Power 2.0, with an α value of 0.05 and 80% power [14].

The eligible participants for this study were judokas who fulfilled the following selection criteria: male adult elite judo players above 18 years of age, reporting no injury within the past six months, and with a minimum black belt ranking (first-dan). The wide age range of participants (18–42 years) was accounted for by ensuring that all were elite judokas with similar competitive experience and skill levels. Statistical analysis was performed to validate results across this diverse group. All participants practiced consistent techniques as members of the Aris Judo Club. This ensured uniformity in training style, though it may limit the generalizability of the findings to other judo populations or training methods. Judokas experiencing shoulder pain were not recruited in this study. These criteria ensured that all selected participants had a high-level technique while performing the studied judo throws, ensuring both athletes' safety and reliable outcomes. If a participant's eligibility was unclear, a consultant sports physician and experienced elite judoka would aid in making a final decision.

The participants were recruited from the Aris Judo Club in Thessaloniki, Greece. A letter was sent to the club informing the president and the instructors about the study and its aims and to request permission to record the participating judokas performing the throws. An information participation sheet was provided to be shared with judokas who were eligible and wished to participate. Finally, informed written consent was obtained from all participants willing to participate before recordings commenced. Further questions in regard to the study were to be answered should the attending judokas had any.

Ethical approval for this cross-sectional study was obtained from the Research Ethics Committee at Queen Mary University of London. The number of the consent form of the bioethics committee is QMREC2014/24/71. The study was conducted in December 2020. Six national team members (elite) competing at an international level (A–F) were recruited for the study.

2.2. Procedures

Data were collected in the Aris Judo Club, in Thessaloniki, and were to be spread over multiple visits, if necessary. Environmental variables, including consistent lighting conditions, standardized floor surfaces, and controlled room temperature, were maintained throughout data collection for consistency. Additionally, the used tatami mats met the International Judo Federation (IJF) competition standards. All the recordings took

place after the training sessions, to avoid judokas' schedules being interrupted and to safeguard that athletes were sufficiently warmed up. The judo club principal as well as the athletes were aware of the date and time of our arrival and performed all throws after being given the participant information sheet and having questions answered prior to filming. Dr. Malliaropoulos was present to tackle any acute injuries or unexpected events during filming.

A Huawei 5T with a 48-megapixel camera was used to record the throws. The phone was set up on a 140 cm height tripod, five meters away from the point where the athletes would perform the throws. This was to ensure that the camera would remain stationary to ensure optimal performance and precise tracking. A camera which captures motion of 30 Hz was used for the final recordings. Although the 30 Hz recording frequency is considered sufficient for basic two-dimensional motion analysis, it introduces limitations in capturing rapid movements. This may have resulted in the underestimation of high-frequency kinematic events, necessitating the use of higher-frequency equipment in future studies to enhance measurement precision. Higher-frequency cameras are recommended for future studies to enhance the precision of kinematic measurements. The Huawei 5T smartphone used for recording throws was equipped with a 48-megapixel camera and captured at a frequency of 30 Hz. While this setup provided sufficient resolution for two-dimensional analysis, it may introduce errors compared to high-speed professional cameras. Additionally, the absence of physical markers on participants, due to the gi uniform, necessitated manual tracking, which could result in a margin of error. To mitigate these limitations, repeated measurements and consistent calibration methods were employed. A one-meter calibration marker was placed at a safe distance from the throwing area to ensure measurement accuracy. The mat on which the throws were performed met the specific recommendations from the International Judo Federation (IJF) and were identical to those used during official judo competitions [15].

Participants gave their age, height, and weight and signed a consent form prior to filming. Based on these data, judokas were organized in pairs in order to be of similar weight to a feasible extent, reflecting the method used in competitions. Six different tori performed three STG throws and three TG throws each within their pair, having a total of 18 throws for each technique. One of the pairs performed an STG throw three times with tori kneeling while performing the throw, resulting in both judokas on the ground after the completion of each throw. This was to observe whether there is a difference in shoulder kinematics between the standing and kneeling STG. Thirty-nine (39) throws were performed in total. Throws that were presented incorrectly or not in frame were repeated, and recordings would be completed when each tori performed three (3) throws on uke. The participant flow chart is found in Figure 4. STG recordings were kept separate from TG recordings to avoid mistakes. Between each throw, participants were given adequate time to rest, before proceeding to the next throw, to ensure their safety and the validity of the technique displayed.

When all recordings were attained and checked for appropriate quality, each throw was uploaded on Kinovea (version 0.8.15) and edited suitably. Kinovea is a piece of software, proven to be a reliable tool, especially in sports science projects and research fields, offering a two-dimensional motion analysis for measuring kinematic parameters [15,16]. The displacement of the shoulder was tracked visually by the researcher in all throws. The impact was defined as the first contact of uke's shoulder with the tatami, measured visually using manual tracking in Kinovea software. Impact was defined as the initial contact point of uke's shoulder with the tatami, measured visually using manual tracking in Kinovea software. This definition ensures consistent identification of the moment of maximum force transfer. Markers could not be added on the participants as they were wearing a gi;

therefore, the reference point was tracked manually by the researcher. The absence of a definition for ‘impact’ meant that we recorded the peak values from any point after uke made initial contact with the tatami.

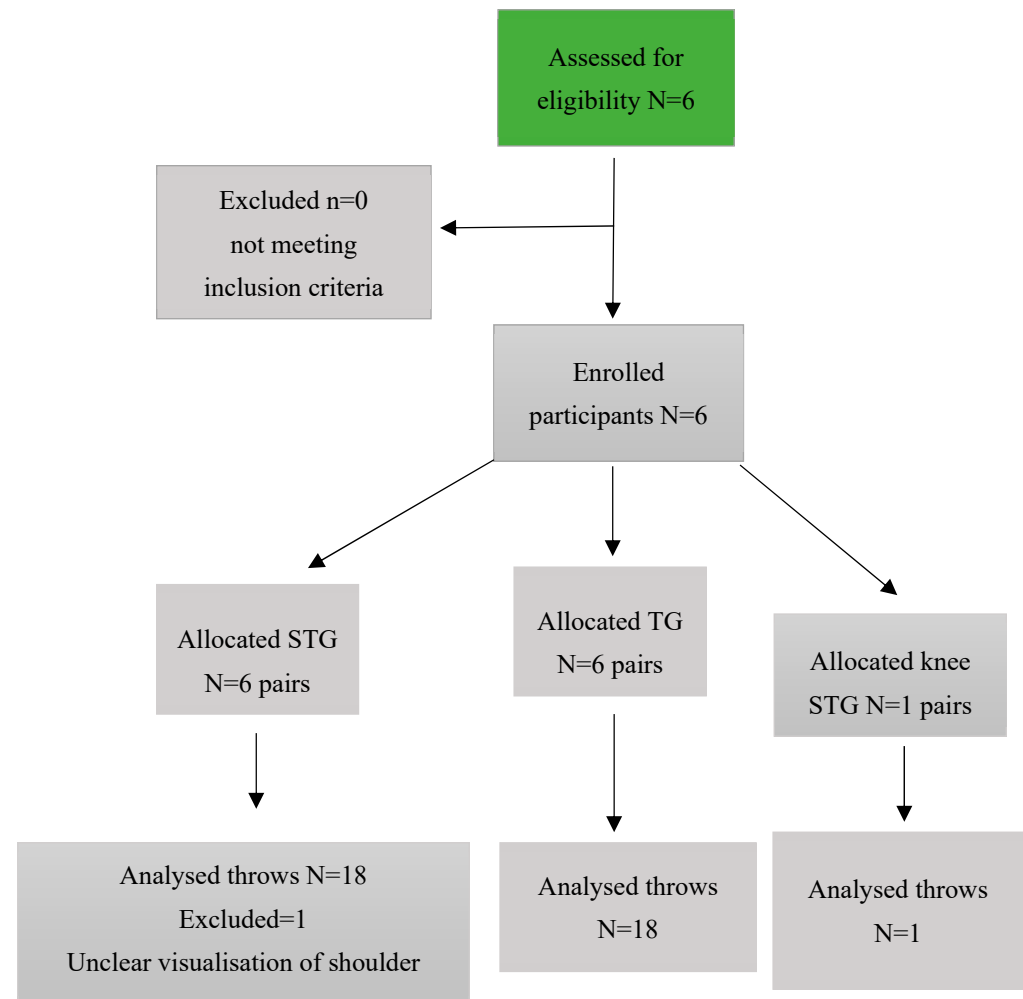


Figure 4. Flowchart of participants.

2.3. Statistical Analysis

Statistical analysis was conducted using IBM SPSS Statistics (version 25.0, Armonk, NY, USA) and Microsoft Excel. Kinovea software and SPSS Statistics are validated tools that are widely used in biomechanical research, meeting the criteria outlined by the International Committee of Medical Journal Editors (ICMJE). These tools were selected based on their reliability and widespread use in sports science research, as recommended by the ICMJE guidelines. A paired *t*-test was used to compare the two measured variables for both throwing techniques, with a significance level of $p < 0.05$. Test–retest reliability was assessed using a two-way random Interclass Correlation Coefficient (ICC) with a 95% confidence interval. ICC values were categorized as low (<0.5), moderate ($0.5–0.75$), good ($0.75–0.9$), and excellent (>0.9). Effect sizes were calculated using Cohen’s *d*, with thresholds of 0.2, 0.5, and 0.8 representing small, medium, and large effects, respectively. The assumptions of the paired *t*-test, including normality (assessed with the Shapiro–Wilk test) and homogeneity of variances (assessed with Levene’s test), were verified before analysis. Given the small sample size, future studies should consider using non-parametric tests, such as the Wilcoxon signed-rank test, or bootstrapping methods to improve statistical robustness. Bootstrapping methods might also improve confidence interval estimates for key parameters, providing a more nuanced understanding of the data. Linear mixed models could also be applied

in future research to assess intra- and inter-individual variability, providing a more nuanced understanding of the data. For analyses involving multiple comparisons, Bonferroni correction was applied to minimize the risk of Type I errors. Additional analyses, such as ANOVA, could be considered in future studies to further strengthen statistical rigor and provide additional insights into the biomechanical differences between techniques [17–20].

3. Results

3.1. Peak Acceleration at Impact

Answering the first questions, the peak acceleration of uke's shoulder in TG ($0.3736 \text{ m/s}^2 \pm 0.0822$) is higher compared to STG ($0.3213 \text{ m/s}^2 \pm 0.0052$). The paired *t*-test revealed this to be statistically insignificant ($p = 0.3$), the test–retest reliability for STG was moderate (ICC = 0.55; 0.01–0.88 95% CI), and that for TG was found to be poor (ICC = 0.42; 0.12–0.83; 95% CI).

Figure 5 illustrates the comparison of mean peak acceleration across the three analyzed techniques: STG, TG, and knee STG. This visual representation highlights the observed differences in acceleration values.

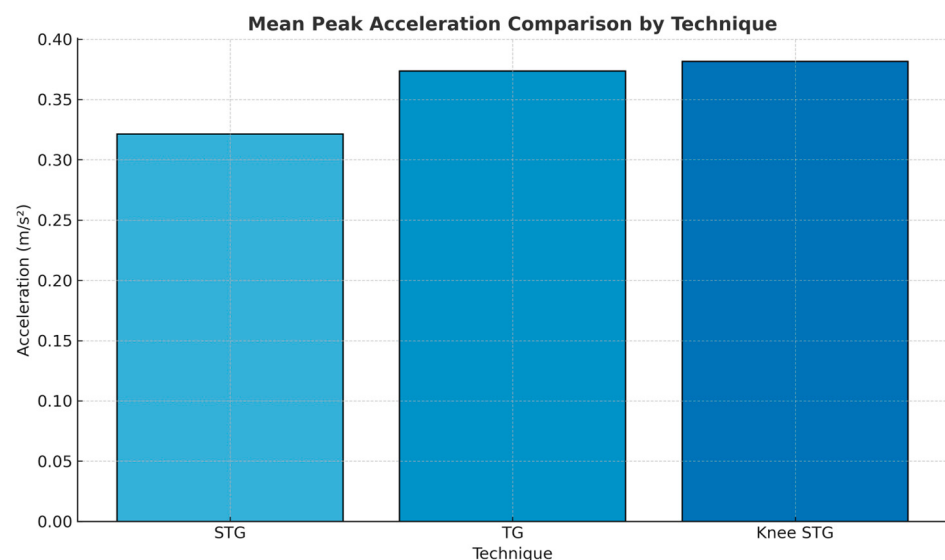


Figure 5. Mean peak acceleration comparison by technique.

The effect size was shown to be medium (Cohen's $d = 0.43$). The peak acceleration ($0.3816 \text{ m/s}^2 \pm 0.0410$) of uke's shoulder when tori performed knee STG was lower than standing STG execution. The individual sample test revealed this to be statistically insignificant ($p = 0.1$). The individual peak acceleration and knee STG values are shown in Table 1 respectively.

Table 1. Mean peak acceleration at impact and peak negative velocity in STG with tori kneeling at landing recorded to four decimal places.

Participant Tori → Uke	Mean Peak Acceleration at Impact in Knee STG (m/s ²)	Mean Peak Negative Velocity in Knee STG (m/s ²)
Tori D → Uke E	0.3816 (0.0410)	−0.0353 (0.0017)

3.2. Peak Negative Velocity at Impact

Figure 6 demonstrates the mean peak negative velocity values for STG, TG, and knee STG, highlighting the statistically significant difference observed in TG.

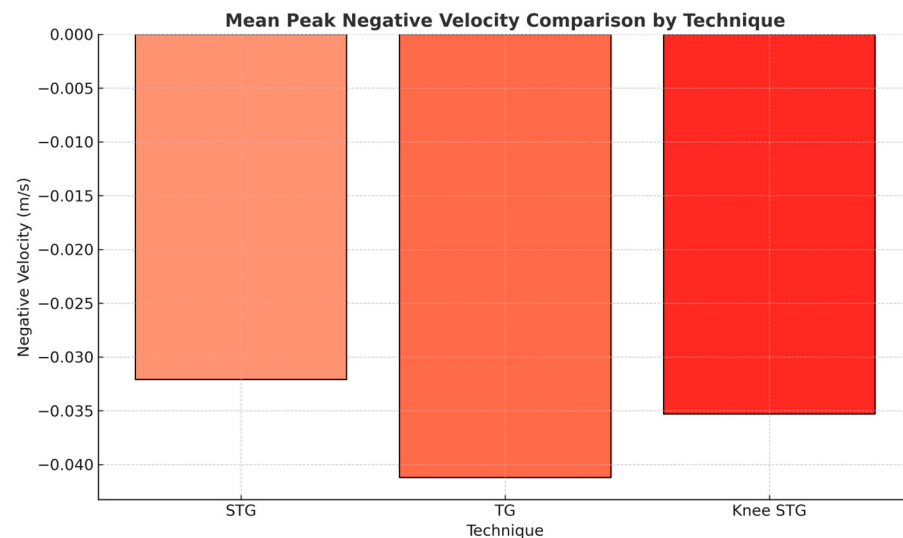


Figure 6. Mean peak negative velocity comparison by technique.

Answering the second question, the analysis revealed that the peak negative velocity of uke's shoulder during TG ($-0.041 \text{ m/s} \pm 0.006$) was significantly higher than during STG ($-0.032 \text{ m/s} \pm 0.005$), with a p -value of 0.04 indicating statistical significance. The test–retest reliability for STG throws was good ($\text{ICC} = 0.74$; $0.31\text{--}0.94$; $95\%\text{CI}$), and that for TG throws was moderate ($\text{ICC} = 0.60$; $0.08\text{--}0.90$; $95\%\text{CI}$). The moderate and low ICC values ($0.42\text{--}0.74$) indicate variability in technique execution, potentially affecting the reliability of the findings. The higher test–retest reliability for STG ($\text{ICC} = 0.74$) compared to TG ($\text{ICC} = 0.60$) may be attributed to differences in technical complexity. The STG technique involves more controlled movements, making it easier to replicate consistently, whereas TG relies more heavily on dynamic adjustments, increasing variability. Cohen's d highlighted a large effect size ($d = 1.12$). The mean peak negative velocity ($-0.035 \text{ m/s} \pm 0.002$) of uke's shoulder when tori performed knee STG was lower than the value of STG performed in standing position. The individual sample test revealed this to be statistically insignificant ($p = 0.2$). The individual peak negative velocity values are shown in detail in Table 2 presents the p values of the acceleration and velocity of the two throws and their statistical outcomes. Table 3 contains the knee STG execution values, while additional details can be found in Table 1.

Table 2. Peak acceleration and peak negative velocity measurements for Sode-Tsurikomi-Goshi (STG) and Tsurikomi-Goshi (TG) throws.

Participant Tori → Uke	Mean Peak Acceleration At impact in STG (m/s^2)	Mean Peak Negative Velocity in STG (m/s)	Mean Peak Acceleration at Impact in TG (m/s^2)	Mean Peak Negative Velocity at Impact in TG (m/s)
Tori A → Uke B	0.2420	−0.0256	0.3523	−0.0341
Tori B → Uke D (STG)	0.2500	−0.0313	0.4288	−0.0391
Tori C → Uke E	0.3173	−0.0319	0.3967	−0.0442
Tori D → Uke C (STG) Tori D → Uke B (TG)	0.3847	−0.0299	0.4611	−0.0517
Tori E → Uke C	0.4515	−0.0415	0.2762	−0.0385
Tori F → Uke B	0.2826	−0.0323	0.3264	−0.0394
AVERAGE (SD)	0.3213 (0.0822)	−0.0321 (0.0052)	0.3736 (0.06842)	−0.0412 (0.0060)
MEDIAN	0.3	−0.0316	0.3645	−0.03925

STG—peak acceleration; TG—peak negative velocity.

Table 3. Mean peak acceleration at impact and peak negative velocity in STG with tori kneeling at landing (D–E) recorded to four decimal places.

	Peak Acceleration TG/STG	Peak Velocity TG/STG	Peak Acceleration Knee STG/Standing STG
<i>p</i> value	0.3	0.04	0.2
Outcome	Statistically insignificant	Statistically significant	Statistically insignificant

The comparison of peak acceleration and peak negative velocity values between standing and kneeling Sode-Tsurikomi-Goshi (STG) throws is presented in Table 3. The results highlight the differences in shoulder kinematics depending on the execution technique. While kneeling STG demonstrated slightly higher peak acceleration and negative velocity values compared to the standing version, these differences were not statistically significant. These findings suggest that the variation in technique execution may influence the biomechanical parameters, but further studies with larger sample sizes are necessary to confirm these observations.

4. Discussion

In our own research, it was assumed that uke's movement was the product of tori's effort to throw uke with no resistance added, and all throws were considered of correct technique execution [11]. The obtained results allow us to verify the hypothesis.

4.1. Biomechanical and Qualitative Analysis

To our knowledge, there is no literature available discussing STG and TG to this date, and this is the first attempt to investigate the velocity and acceleration values of judo athletes' shoulders coming to contact with the tatami. For this reason, this is innovative research in judo research and sports medicine. Both techniques are frequently practiced in judo competitions and, therefore, research on the impact forces and analysis of the velocity and acceleration values are important steps for the assessment of the risk of injury. The biomechanical analysis showed greater peak acceleration and velocity values in TG (0.374 m/s^2 , -0.041 m/s) compared to STG (0.321 m/s^2 , -0.032 m/s). Future studies should explore whether such differences translate to real-world scenarios, such as competition-induced injuries. Defining key terms such as "impact" and "negative velocity" more explicitly within the context of judo throws would provide greater clarity for readers. Using annotated images or diagrams to highlight kinematic differences between STG and TG techniques could also enhance the visual understanding of these movements. In particular, peak negative velocity was the result to be significantly different ($p = 0.04$). These data suggests that uke is thrown faster by tori in TG [5,8,16,21]. In the same manner, greater values were observed in knee STG (0.382 m/s^2 , 0.035 m/s), compared to standing STG (0.276 m/s^2 , 0.321 m/s). However, the difference was insignificant ($p = 0.1$, $p = 0.2$, respectively).

On a qualitative level, a notable difference between the throws is that in STG, tori holds uke from their sleeves, each hand holding the opponent's sleeve, before turning 180 degrees (wide stance) to throw them on the ground. Accordingly, in TG, one of tori's hands holds uke from the gi collar, and the other hand holds uke from their sleeve, following the same pattern of throwing. Even though the technique execution is similar between the throws, it is differentiated as to where tori is gripping uke. This essentially means that in TG, uke's head momentum is more determined by tori, as the gripping area (collar) is closer to the head and therefore to the body's center of mass (Figure 3). Also, the fact that tori is gripping uke from both sleeves in STG gives uke less control over the landing arm movement and, therefore, the shoulder placement at the point of landing. At the same time, the end-of-sleeve grip in STG gives better control of uke's arm for tori in order to proceed with a

long pull, in contrast with TG, where tori must execute the throw quickly, since a collar grip indicates throwing uke [22]. This could explain the difference, albeit insignificant, in peak acceleration between the throws. To provide a deeper understanding of the results, future studies should integrate advanced musculoskeletal modeling to analyze shoulder stress mechanisms. For example, factors such as muscle contraction patterns, joint rotation angles, and speed should be examined to explain the uneven stress observed in different throwing techniques.

When comparing standing with knee STG throws, uke's shoulder reaches a greater vertical height in standing STG, which gives the shoulder greater potential and ultimately kinetic energy and momentum at impact. The peak velocity would then be greater at the moment of impact, producing greater impact forces [23]. While this study did not directly measure impact forces, the significant differences in velocity suggest a higher rate of momentum change during TG throws. This indicates a potential for greater impact forces, warranting further research to quantify these forces and explore their implications for injury prevention.

4.2. Forces at Impact

According to Newtonian physics, acceleration and velocity are proportional to impact forces. Our data indicate that the statistically significant differences in velocity between throws may correspond to greater impact forces, which would be interpreted as greater velocity equaling greater force and therefore greater risk of injury. A critical factor in reducing the risk of shoulder injuries in judo is the proper execution of ukemi, the breakfall technique. Ukemi allows judokas to distribute the impact forces over a larger surface area of the body, reducing the stress applied to specific joints, such as the shoulder. Studies have shown that judokas who master ukemi are less likely to suffer from severe shoulder injuries, as the technique minimizes direct collisions between the shoulder and the tatami [24].

In our analysis, although the acceleration in TG was greater than STG, the difference was found to be statistically insignificant. Discrepancies between acceleration and negative velocity results likely reflect differing biomechanical demands inherent to each technique. Negative velocity is directly influenced by the speed of rotation and the angle of uke's body during the throw, whereas acceleration is affected by the initial force applied by tori. Larger sample sizes or comparisons across athletes of different levels may reveal statistically significant differences in these indicators. On this basis, our analysis cannot be certain that there is a significant difference on impact forces between the two throws, and further research, potentially with a greater sample size, could present additional scientific input on the matter.

Impact forces are also dependent on the rigidity of colliding surfaces, which, in our case, are uke's shoulder and the tatami. Rigidity determines the stopping distance (d), which is the distance travelled after impact and is inversely proportional to impact forces. This means that during a collision, the greater the rigidity, the less elastic the collision will be and, therefore, greater momentum will transfer at impact, and, hence, greater forces are to be developed to the body [25,26].

4.3. Pairing Participants

There is a suggestion that participants' characteristics explain the velocity results in our study. The weight categories in individual competitions are ≤ 66 , ≤ 73 , ≤ 81 , ≥ 90 , and ≥ 100 kg [3]. Had the pairs been in a competition setting, two pairs would compete in the same category (C-109 kg/E-104 kg, B-73 kg/F-79 kg). Strength has been associated with an advantage in judo and, more specifically, the strong development of arm and shoulder muscles allow for more effective performance. Static strength is linked with adequate

body mass; it has, however, a negative impact on strength endurance [27]. STG and TG being hip throws, they create large collisions compared to other types onto uke and are considered suitable for stronger and heavier players. Furthermore, both techniques include tori lifting and maneuvering uke, which requires arm, trunk, and leg strength to carry the weight (Figures 1 and 2) [11]. On this basis, we can hypothesize that heavier and therefore possibly stronger judokas will be more successful in the efficient completion of these throws. However, there is no apparent model to propose this.

4.4. Addressing the Injury Issue

Modifications in judo techniques can have a positive impact on the moderation of shoulder impact forces. A common technique is ukemi (breakfall), which allows the stress applied to the body to dissipate at the moment of contact with tatami [6,28]. Studies on judo techniques consider ukemi a preventative method and have been able to identify poor technique, in novice judokas, and link it with injury [6,24,29]. Although this study recruited elite judokas with correct technique performance, it is important for coaches to ensure individuals' safety at all times [29–31]. Adjustments mentioning the under-mat presence has also been discussed as a factor influencing the injury risk, as it believed to have a shock-absorbing effect that ultimately reduces impact forces to a certain extent. However, Okuyuku mentions that a supportive mat is not sufficient to protect from severe head injuries. Protective equipment is also recommended in some studies. However, its efficiency still remains unclear [5,30]. Based on the findings, adjustments to judo training systems, such as emphasizing ukemi techniques at all skill levels, could significantly reduce shoulder injury risk. Additionally, the use of impact-absorbing mats during training and modifications to competition rules to minimize high-impact throws should be considered.

An essential point to consider is that in studies analyzing nage-waza judo techniques, uke presents no resistance when being thrown [32]. This is not the case neither in official competitions nor in real-life training, as uke resists being taken down to prevent point winning. Having that in mind, uke does not concentrate completely on ukemi and, therefore, the correct performance of the breakfall is impeded. Consequently, this is important point to be considered, as part of the establishment of preventative strategies of risk injury and further research to be implemented to athletes when under competition circumstances for more pragmatic values [33–35].

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

4.5. Limitations

This study has several limitations. One key limitation is the potential for visual inaccuracies in tracking shoulder displacement. Due to participants wearing gi uniforms, markers could not be placed directly on their bodies, necessitating manual tracking of reference points using Kinovea software. This method may have introduced small errors in displacement measurements, particularly in high-velocity scenarios. Additionally, the absence of a precise definition for the “point of impact” may have affected the consistency of data calibration, as the exact moment and location of shoulder contact with the tatami could vary between throws. These factors could have influenced the reliability and precision of the recorded kinematic values.

Another limitation is the small sample size, consisting of six elite male judokas recruited from a single judo club. This limits the representativeness of the findings, as training methodologies and techniques can vary across clubs. Future studies should include ath-

letes from multiple clubs and varying competitive levels to ensure broader applicability. The small sample size also reduces the statistical power of the study, potentially missing variability in shoulder kinematics. Furthermore, the lack of female athlete representation restricts the generalizability of the findings. Future research should prioritize recruiting a larger and more diverse sample, including athletes of different genders, skill levels, and competitive backgrounds, to provide comprehensive insights into the biomechanical aspects of judo throws.

To improve data accuracy, future studies should consider using three-dimensional motion analysis or marker-based systems to enhance the precision of kinematic tracking. Direct measurements of impact forces are also recommended to validate inferences drawn from velocity and acceleration data regarding injury risks. Additionally, the lack of control over participants' weight categories may have introduced variability into the results, as body mass significantly influences the dynamics of judo throws. Including weight categories in future research would help reduce variability and improve the robustness of findings.

4.6. Recommendations

Future biomechanical investigations should continue to explore shoulder injury mechanisms in judo. Athletes and coaches should emphasize safety measures, particularly correct ukemi techniques, to prevent injuries. The use of under-mats and protective equipment should also be considered, with further studies evaluating their effectiveness in minimizing shoulder injury risks.

5. Conclusions

Shoulder injuries are common in judo, and by understanding the underlining mechanisms, strategies can be considered to reduce the risk of injury. Our biomechanical analysis showed the negative peak velocity on uke's shoulder in STG to be greater in comparison to TG and this difference to be statistically significant. This would reveal that uke is thrown quicker by tori in TG, given the nature of the technique. The acceleration of uke's shoulder in STG was found to be greater; however, there was no statistical significance in the compared results. Greater peak negative velocity suggests a greater rate of momentum change and therefore higher applied forces, although they are inconsistent with acceleration. Evidently, further research should be carried out on the impact force estimations to determine the effective mass of uke's shoulder. The practical application of these findings includes developing targeted training programs to improve throwing efficiency while minimizing injury risks. Coaches should focus on biomechanically optimized techniques and preventative measures, such as proper warm-ups and impact force reduction strategies, to enhance athlete safety and performance.

Further research on techniques performed with various executions are also to be considered, similarly to knee and standing STG, to cover most variations of judo throwing techniques. In the meantime, attention must be given towards ukemi techniques and the use of under-mat as potential ways of minimizing impact forces at landing.

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