

# **Bilateral Deficit in the Countermovement Jump and its Associations with Judo-Specific Performance**

Rafael L. Kons<sup>1</sup>, Jonathan Ache-Dias<sup>2</sup>, Rodrigo G. Gheller<sup>1</sup>, Chris Bishop<sup>3</sup> & Daniele Detanico<sup>1</sup>

<sup>1</sup>Biomechanics Laboratory, Center of Sports, Federal University of Santa Catarina, Santa Catarina, Brazil

<sup>2</sup>Research Group on Technology, Sport and Rehabilitation, Catarinense Federal Institute, Araquari, Santa Catarina, Brazil

<sup>3</sup>Faculty of Science and Technology, London Sport Institute, Middlesex University, London, United Kingdom

## **Corresponding author:**

Rafael Lima Kons

Federal University of Santa Catarina, Center of Sports, Biomechanics Laboratory

ZIP-CODE: 88040-900, Florianópolis, Santa Catarina, Brazil.

Phone: +55 48 3721-8530

E-mail address: [rafakons0310@gmail.com](mailto:rafakons0310@gmail.com)

## **ORCID:**

Rafael L. Kons: <https://orcid.org/0000-0003-1615-5464>

Jonathan Ache-Dias: <https://orcid.org/0000-0001-9146-9450>

Rodrigo G. Gheller: <https://orcid.org/0000-0002-2259-8096>

Chris Bishop: <https://orcid.org/0000-0002-1505-1287>

Daniele Detanico: <http://orcid.org/0000-0001-6127-437X>

**Disclosure statement:** No potential conflict of interest was reported by the author(s).

**Acknowledgments:** The authors acknowledge all volunteer participants for their collaboration

**Funding:** Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES)

Finance Code 001

## **Abstract**

This study aimed to describe the bilateral deficit (BLD) during the countermovement jump (CMJ) in judo athletes and determine the relationship between the BLD and judo-specific performance. Fourteen male judo athletes participated. The athletes performed three specific judo tests: Maximal Sprint Speed Judo Test, Maximal Aerobic Speed Judo Test, Special Judo Fitness Test (SJFT), and double- and single-leg CMJ. The following CMJ variables were used: jump height JH, mean – MPO and peak – PPO power output, peak force – PF, peak velocity – PV and impulse – IMP. The Pearson's or Spearman's test were used ( $p < 0.05$ ). The results show that the BLD is found in all CMJ parameters (27% in JH; 20% in MPO; 22% in PPO, 61% in PF, 41% in PV and 31% in IMP). Negative correlations between first set of SJFT<sub>TT</sub> (total throws) and BLD in PF ( $r = -0.60$ ;  $p = 0.022$ ) and between the second set of SJFT<sub>TT</sub> and BLD in MPO ( $r = -0.74$ ;  $p = 0.002$ ), PV ( $r = -0.59$ ;  $p = 0.025$ ) and IMP ( $r = -0.55$ ;  $p = 0.040$ ) were found. Also, negative correlations between SJFT<sub>TT</sub> and the BLD in all CMJ parameters ( $r = -0.53$  to  $-0.85$ ;  $p < 0.05$ ) were found. The BLD in most CMJ variables is negatively correlated (large to very large) to the SJFT<sub>TT</sub>. So, high BLD values are related to poor SJFT<sub>TT</sub> performance.

**Keywords:** Combat sports, muscular imbalance, lower limb, vertical jumping.

## Introduction

Sport-related performance is dependent on factors that consider several skills and physical attributes (Chaabene et al., 2018). In combat sports such as judo, high-intensity actions are present during both matches and training sessions (Franchini et al., 2011; Franchini et al., 2013), with the upper and lower limbs constantly in use (Detanico et al., 2012; Kons et al., 2018). Pulling and pushing actions are frequently performed during matches and training, primarily in the upper limbs and movements with change of directions are often performed by the lower limbs to execute sport-specific techniques and tactical strategies (Kons et al., 2018). To identify parameters related to specific performance for judo athletes, the inclusion of previously validated sport-specific tests or measures (e.g. Maximal Sprint Speed Judo Test, Maximal Aerobic Speed Judo Test and Special Judo Fitness Test – SJFT), help to retain a high level of ecological validity when profiling an athlete's athletic ability (Chaabene et al., 2018; Del Vecchio et al., 2014; Franchini et al., 2009; Shiroma et al., 2019).

It is already known the important role of the lower limbs play on the performance of judo (Franchini et al., 2011), which is elucidated by the relationship of the vertical jump performance (e.g. jump height) with the specific performance in judo actions (e.g. number of throws) (Detanico et al., 2012) and the overall effectiveness combat time during official judo competitions (Kons et al., 2017). Some studies (Detanico et al., 2015; Kons et al., 2018; Kons et al., 2021a) have demonstrated that the high demand of the lower limbs in judo induces the accumulation of fatigue in lower limbs during successive judo matches. In addition, the accumulation of fatigue from successive high-intensity efforts has been indicated as a factor in the onset of muscular imbalance and consequently increases in lower limb asymmetry (Bishop et al., 2019), specifically in judo athletes (Kons et al., 2021; Kons et al., 2020). Furthermore, higher values of lower limb asymmetry in jump height have been shown to be negatively related to the number of total throws in SJFT performance ( $r = -0.68$ ) for judo athletes (Kons et al., 2019). However, little is known about the others aspects related to muscular imbalances in the lower limbs as the bilateral deficit (BLD).

The phenomenon of muscle imbalance that considers both unilateral and bilateral performance (Janzen et al., 2006) has been evaluated by the BLD (Howard & Enoka, 1991). The BLD indicates that force production during a maximal bilateral contraction is lower than the sum of total force produced by the left and right limbs combined (Bishop et al., 2009; Bobbert et al., 2006; Botton et al., 2013; Bracic et al., 2010). The BLD analysis can be performed in different types of exercises and variables (*e.g.* power and velocity), with research to date mainly focused on isometric (Botton et al., 2013; Botton et al., 2013), isokinetic (Janzen et al., 2006; Magnus & Farthing, 2008) and jumping (Bishop et al., 2019; Bracic et al., 2010) exercises. According to Bishop et al. (2019), the existence of the BLD, may be related to different mechanisms such as: changes in motor unit recruitment, neural mechanisms, limb dominance and aspects related to specific training adaptations (*i.e.* training preference for bilateral or unilateral movements during sports practice). Therefore, the BLD is a multi-factorial phenomenon influenced by different parameters related to neuromuscular performance.

The muscular imbalance in judo athletes has been investigated in recent years, with a greater focus on measures of unilateral performance and the subsequent inter-limb asymmetry (Kons et al., 2019; Kons et al., 2020; Kons et al., 2021). However, as far as we know only one study has analyzed the BLD phenomenon in judo and found no correlation between BLD (isometric handgrip strength test) and SJFT performance (Turnes et al., 2020). Although the study did not find a correlation between the BLD and SJFT, this characteristic may be different for the lower limbs and needs to be investigated. It has been suggested that lower limb BLD may be a factor of consideration, according to the specific characteristics of certain sports (Bishop et al., 2019; Kozinc & Sarabon, 2021; Ascenzi et al., 2020). Therefore, considering that judo is a sport in which the lower limb muscle power is critical (Detanico et al., 2012) and that it was negatively associated with vertical jump asymmetry (Kons et al., 2019), to identify the relationship between lower limb BLD and judo performance could provide important information for practitioners about the neural adaptations of both unilateral and bilateral efforts.

Therefore, the objectives of this study were to: 1) verify the presence of BLD during vertical jump assessments in judo athletes and, 2) verify the relationship between BLD and judo-specific performance. Our hypothesis is that BLD values are negatively associated with performance in judo-specific tests, since there is already evidence that muscle imbalance parameters are detrimental to judo performance (Kons et al., 2019).

## **Methods**

### **Participants**

Fourteen male judo athletes participated of this study, presenting the following characteristics:  $25.2 \pm 2.2$  years,  $77.4 \pm 20.3$  kg,  $1.78 \pm 0.6$  m,  $15.1 \pm 4.2\%$  of body fat and  $14.7 \pm 3.6$  years of judo practice. The sample size was determined a priori using the GPower 3.1 software, taking as reference a probability of .05 (minimum error type I), statistical power of 0.8 (minimum error type II), and effect size of 0.5 (mean effect). Thus, the minimum sample size for the correlation tests were 19 participants being close to the sample of this study. All athletes competed at national tournaments and were engaged in regular training (technical-tactical and physical training) 3-4 times a week, at either brown or black belt levels. The inclusion criterion was: to report no musculoskeletal disorders or injuries at least one year before the evaluations, or physical restrictions that could influence their maximal performance, and be training at either brown or black belt levels. Participants were instructed not to intake alcohol or medication for at least 48-h before and during the evaluations, and to maintain their normal diet. Before the assessments, all participants were informed about the procedures and signed an informed consent form. This study was approved by the Research Ethics Committee of the local University, in accordance with the Declaration of Helsinki.

### **Experimental Design**

This is a cross-sectional study in which athletes performed bilateral and unilateral countermovement jumps (CMJs) and the follow judo-specific tests: Maximal Sprint Speed Judo Test, Maximal Aerobic Speed Judo Test, and Special Judo Fitness Test. Participants visited the laboratory on four occasions: two days for familiarization with the test protocols and two days for testing. In the first visit, athletes were provided with an explanation about the purpose of the study and with the familiarization protocol, which consisted of three sets of 15 repetitions of the judo-specific movement denominated *uchi-komi hikidashi* (since this technique is performed during the MSSJT and MASJT test protocols), and three sets of five repetitions for the specific technique used in SJFT (e.g. *ippon seoi nage*

technique). In the second visit (48-h after), the athletes performed a familiarization involving 30 seconds of hopping on a trampoline, three series of 10 hops on the ground, and five maximal efforts bilateral and unilateral CMJ. In the third and fourth visits, data was collected for bilateral and unilateral CMJs, and the judo-specific tests.

## **Procedures**

### *Anthropometric assessment*

Body mass and height of participants were measured with a digital scale (0.1 kg resolution) and a stadiometer (0.1 cm resolution), respectively. The equation proposed by Petroski and Pires-Neto (1996) was used to estimate the body density of athletes, which considers the sum of four skinfold thicknesses (triceps, subscapular, suprailiac, and medial calf). All measurements were performed before the physical tests by an experienced evaluator (level 1 of the International Society for Advancement in Kinanthropometry). The procedure of three sequential measurements was used for the skinfold thicknesses, being considered the average for the analysis. Body fat percentage was then calculated using the Siri equation (Siri, 1961).

### *Bilateral and Single Leg Countermovement Jumps*

Athletes were asked to stand in the center of a piezoelectric force platform (Model 9290AD, Quattro Jump, Winterthur, Switzerland) with hands on their hips. For both bilateral and unilateral jump assessments, subjects performed a countermovement, followed by a rapid extension of the lower limb joints, with the intention of jumping as high as possible. The athletes were verbally encouraged during data collection and instructed to jump using a preferred squat depth to avoid any alterations in preferred jump strategy. Each individual performed three maximal single leg CMJ on dominant and non-dominant limbs and three bilateral CMJ, in a randomized order. The ground reaction force (GRF) data was registered and filtered by a fourth-order low-pass Butterworth filter at 20 Hz, determined from power spectral analysis. The CMJ parameters obtained from the force-time curve were: a) jump height – highest value of the curve obtained by double mathematical integration of the GRF in time;

b) peak and mean power output - calculated by multiplying the GRF by velocity in concentric phase of the jump; c) peak force - highest value obtained in the concentric phase of the jump; d) peak velocity - highest value obtained in curve of velocity, observed immediately before the loss of foot contact with the ground (take-off) and; e) vertical impulse - determined during the concentric phase of the jump.

#### *Bilateral Deficit Calculation*

The magnitude of the BLD was calculated as a percentage using the equation proposed by Rejc et al. (2010) and used in similar study by Bishop et al. (2020) being:  $BLD = 1 - (\text{bilateral}/(\text{right} + \text{left})) \times 100$ . A positive percentage score indicates the presence of a BLD, whereas a negative percentage is indicative of a bilateral facilitation (BLF), where the bilateral performance is superior to the summed unilateral performance (Bishop et al., 2019; Kozinc & Sarabon, 2020).

#### *Maximal Sprint Speed Judo Test*

After a specific warm-up (five sets of five low-intensity hikidashi repetitions interspersed by 20 s of passive recovery) the athletes performed the Maximal Sprint Speed Test as suggested by Del Vecchio et al., (2014) and adapted from Kons et al., (2021b) and Franchini et al., (2021). The test consisted of five repetitions set of judo-specific movement (*hikidashi*) at all-out intensity. All athletes wore a *judogi* and maintained the same pairs (similar body mass and height) during this test. The time, in decimal seconds, of the repetitions of *hikidashi* was measured during the protocol using a digital timer (Casio, hs-3 V, Tokyo, Japan). The intraclass Correlation Coefficient (ICC) was calculated from the two conditions (familiarization and test) and the result was 0.94 in previous study (Franchini et al., 2021).

#### *Maximal Aerobic Speed Judo Test*

The maximal aerobic speed test was performed using the specific judo technique (*hikidashi*). In judo, this movement represents the preparation phase of many judo techniques. During execution of this test, an evaluator monitored the correctness of the technique execution, which consisted of three phases: initial position, pulling the sleeve with concomitant hip rotation, and returning to the initial



position after the technique execution. The initial speed was set at 32 rep/min and each stage lasted one minute with three rep/min increments as described by Shiroma et al. (2019). The speed was controlled using a metronome (Metronome Tempo Lite App, Frozen Ape, Hougang, Singapore), and the judo athlete, coinciding with the initial and intermediate position (two beeps for each repetition), should follow the rhythm. The test was finished when athletes requested to stop or could no longer maintain the established speed, and the speed of the last stage was considered as the maximal aerobic speed test. This test presents a good reliability (ICC = 0.81), lower typical error (TE = 1.58) and lower coefficient of variation (2.77%), as demonstrated by Shiroma et al. (2019).

### *Special Judo Fitness test*

Initially, was performed a standardized joint warm-up, followed by five minutes of recovery period. Three athletes of similar body mass and height performed the SJFT according to the following protocol: two judokas (uke) were positioned at a distance of six meters from each other, while the test executor (tori) was positioned three meters from the judokas to be thrown. The procedure was divided into three periods —15 seconds (a), 30 seconds (b), and 30 seconds (c) — with 10-second intervals between them. In each period, the executor throws the opponents using the *ippon-seoi-nage* technique as many times as possible. Performance was determined based on the total throws completed during each of the three periods (A + B + C). The heart rate was measured immediately after the test and then one minute later (Polar Vantage NV, Kempele, Finland). The index was calculated through the sum of HRs (immediately after the test and one minute later) divided by the total number of throws (Franchini et al., 2009).

### **Statistical Analyses**

The intraclass correlation coefficient (ICC<sub>3:1</sub> – consistency) and typical error (TE) were used as relative and absolute reliability indicators, respectively, for all CMJ parameters. The ICC and TE were calculated from the three trials before testing. TE was calculated by dividing the standard deviation (SD) of the difference between three trials (pre-condition) by  $\sqrt{2}$  with a 95% confidence

interval (CI) (Hopkins, 2000) and expressed as a coefficient of variation (CV). For interpretation of ICC values the following criteria were used: > 0.9 excellent, 0.75–0.9 good, 0.5–0.75 moderate, and < 0.5 poor (Koo & Li, 2016) and TE values were considered acceptable if lower than 10% (Cormack et al., 2011). Data normality was tested using the Shapiro-Wilk test and the equality of variances assumption using Levene's test. Pearson's linear correlation or Spearman's correlation were used to verify the correlation between BLD and judo-specific tests performance, depending on the normality of the data. The criterium adopted to classify the magnitude of effects was  $r$ : 0 to 0.1 (trivial), 0.1 to 0.3 (small), 0.3 to 0.5 (moderate), 0.5 to 0.7 (large), 0.7 to 0.9 (very large), and 0.9 to 1.0 (almost perfect) (Hopkins, 2002). To compare the percentage of each BLD in CMJ parameters, the Friedman test with Conover's post hoc (non-parametric analyses) was used. The ES for this test was derived from Friedman Chi Square ( $X^2$ ) and calculated from the omega squared ( $u^2$ ) with the criterion classification: < 0.01 very small, 0.06 small, 0.14 moderate and > 0.14 large. All statistical analyses were conducted in the JASP software (version 0.11.1, University of Amsterdam, Netherlands).

## Results

Table 1 shows the mean, SD, reliability and TE CMJ parameters (jump height, mean power, peak power, peak force, peak velocity and impulse). The results demonstrated good to excellent reliability for all parameters (ICC = 0.89 to 0.99) for single leg and bilateral jump performance. The TE for all parameters was 1.17 to 9.40%; thus, being acceptable for all variables (> 10%). In the table 2 is presented the descriptive results (mean, SD, minimum and maximum) of judo-specific tests.

*\*\*Insert Table 1 Here\*\**

*\*\*Insert Table 2 Here\*\**

Figure 1 shows the BLD percentages for the CMJ parameters (jump height, mean power, peak power, peak force, peak velocity and impulse). A BLD was present in all parameters: jump height ( $27.82 \pm 14.50\%$ ), mean power ( $20.15 \pm 13.11\%$ ), peak power ( $22.83 \pm 20.21\%$ ), peak force ( $61.08 \pm 13.79\%$ ), peak velocity ( $41.66 \pm 9.05\%$ ) and impulse ( $31.48 \pm 17.78\%$ ). The Friedman test demonstrated significant difference in the magnitude of BLD ( $X^2_{(4,52)}=53.06$ ,  $p < 0.001$ ,  $\eta_p^2=0.88$  [large effect]). The Conover's post hoc demonstrated high BLD percentage for peak force compared to the BLD in jump height ( $p < 0.001$ ), BLD in mean power ( $p < 0.001$ ), BLD in peak power ( $p < 0.001$ ) and BLD in impulse ( $p = 0.009$ ), but no difference for BLD in velocity ( $p = 0.47$ ) was found. Finally, BLD in velocity was higher compared to the BLD in mean power ( $p = 0.007$ ) and BLD in peak power ( $p < 0.001$ ), for the other BLD percentage no difference was found ( $p > 0.05$ )

*\*\*Insert Figure 1 here\*\**

Table 3 summarizes the correlation values between BDL and judo-specific performance. Significant negative correlation was found for mean power BDL and SJFT<sub>B</sub> ( $p = 0.002$ ; very large), SJFT<sub>TT</sub> ( $p < 0.001$ ; very large) and SJFT<sub>INDEX</sub> ( $p = 0.004$ ; very large). Moreover, negative and significant

correlations were found between jump height deficit and SJFT<sub>TT</sub> (p = 0.018; large), peak power BDL and SJFT<sub>TT</sub> (p = 0.048; large), peak force and SJFT<sub>A</sub> (p = 0.022; large), SJFT<sub>TT</sub> (p = 0.006; very large) and SJFT<sub>INDEX</sub> (p = 0.024; large), and finally between peak velocity and SJFT<sub>B</sub> (p = 0.025; large), SJFT<sub>TT</sub> (p = 0.003; very large) and SJFT<sub>INDEX</sub> (p = 0.015; large). The impulse was related to SJFT<sub>B</sub> (p = 0.040; moderate), SJFT<sub>TT</sub> (p = 0.018; large) and SJFT<sub>INDEX</sub> (p = 0.015; large).

*\*\*Insert Table 3 here\*\**

## Discussion

The aim of this study was to verify the presence of the BLD during the CMJ in judo athletes and determine its relationship with the judo-specific performance. Our hypothesis was accepted as the BLD was present in all CMJ parameters and significant correlations between BLD and SJFT performance (throws and index) were found.

The results of the study show that in all of the CMJ parameters the BLD is present, and the highest values in the peak force and velocity parameters, as can be observed in Figure 1. In this sense, each parameter represents different mechanical and physiological aspects related to CMJ performance (Cohen et al., 2020; Linthorne et al., 2001), and assessments that utilize unilateral or bilateral jumps may provide different results for each parameter. Cohen et al. (2020) verified that movement velocity is slower and force production is higher during unilateral CMJ compared to its bilateral counterpart, due to the challenge of maintaining the balance and a possible influence of knee flexion during CMJ preparation (Gheller et al., 2015). Thus, it seems that peak force and velocity were more affected when the BLD was analyzed. In support of our results, Bishop et al. (2020) analyzed the CMJ in healthy university students and found BLD values similar to the current study (19.5% in peak power and 31.9% in impulse), but lower values for jump height (12.6%). Although somewhat anecdotal, the greater BLD values for jump height could be due to the superior athlete status of the sample in the present study, which seems like a plausible explanation given students were used in the study by Bishop et al. (2020).

Although it was found a large to very large correlation between BLD and SJFT, the same results were not evident with the MSSJT and MASJT. These results may be explained by the characteristics of the MSSJT and MASJT, whereby no specific judo movements such as throws are required. These results demonstrated that athletes with higher values of BLD in the all CMJ parameters showed a lower performance in SJFT<sub>TT</sub> (that consider the total throws) and lower performance in SJFT<sub>INDEX</sub>. In this sense, the higher the SJFT<sub>TT</sub> value, the better performance in the specific task (throws using a specific technique) (Lopes-Silva et al., 2021; Kons et al., 2020). The

high-intensity actions during judo matches or training may contribute to the muscle imbalance between the limbs, as the preferred side is required more during attacks (Sogabe et al., 2015), especially in regard to leg throwing techniques (*e.g.*, o-soto gari, uchi-mata, sassae-tsurikomi-ashi, etc.) and some hip throwing techniques (*e.g.*, harai-goshi, hane-goshi, etc.). In turn, this may have been a related factor for the magnitude of BLD in judo athletes. In the same direction, considering the consistencies of the relationships between the CMJ parameters and the performance in the SJFT<sub>TT</sub>, we can infer that judo athletes are required to be very strong, stable, and powerful on two limbs, in order to maximize their chance of both successful defense and attack during judo specific actions (Kons et al., 2018), for this perspective, it's may be favorable to reduce the deficit (*i.e.*, get better at bilateral jumping more than unilateral jumping), in order to optimize judo-specific performance.

The SJFT<sub>TT</sub> is widely used to access physical performance in judo athletes (Sterkowicz-Pryzbician et al., 2019; Lopes-Silva et al., 2020; Kons et al., 2018; Kons et al., 2019) and its performance has been associated with several variables, including jump height (Detanico et al., 2012) and an overall effective judo time obtained in official judo competitions ( $r= 0.69$ ) (Kons et al., 2018). Recently, the SJFT<sub>TT</sub> values were negatively associated with CMJ asymmetry ( $r = -0.68$ ) (Kons et al., 2019), suggesting that muscle imbalances also seem to be related to lower performance in judo-specific tasks, such as successive throws. Similar results have been reported in other sports (*e.g.* soccer, sprinters, tennis and basketball players) (Ascenzi et al., 2020; Bračić et al., 2010; Kozinc & Sarabon, 2021), demonstrating that this phenomenon seems to be related to specific training adaptations (*i.e.* training preference for bilateral or unilateral movements during sports practice). On the other hand, the SJFT<sub>INDEX</sub> represents the combination of aerobic and anaerobic capacity, (Franchini et al., 2009; Franchini et al., 2011) and so, it is possible that higher BLD values in the CMJ may be related to poor performance in judo throwing techniques, especially those involving powerful actions and aspects related to the stretch-shortening cycle performance (Detanico et al., 2012; Kons et al., 2018), which are identified in several judo techniques (Detanico et al., 2012; Zaggelidis et al., 2011).

Regarding the SJFT, it should be highlighted that despite the BLD presented in jump height, peak power, peak force and impulse have presented large correlation with SJFT<sub>TT</sub>, our data shows that the mean power output presented very large correlation. So, although the jump height is considered the outcome measure of a vertical jump (Kons et al., 2017; Markovic et al., 2007; Dal Pupo et al., 2021) and is the most accessible for all practitioners, the BLD calculated for this metric was not as strongly associated with judo-specific performance, as mean power output.

Our study has limitations that need to be commented. First, only the CMJ parameters were used to calculate the BLD, although the CMJ is considered a good test for evaluating the BLD (Bishop et al., 2019; Bracic et al., 2010), other lower limb tests such as the standing long jump, drop jump or unilateral isometric squat test may be alternative options. Second, despite the enough statistical power (>0.8) and composed by high-trained judo athletes, a small sample size (n=14) was investigated. Third, it was not possible to access the BLD during official judo matches due to the characteristics of judo tasks that make assessment difficult.

It is recommended that future studies use a larger sample size, considering age groups (e.g. U18 and U21) and sex (male and female), which will provide a useful base when trying to understand the relevance of the BLD evaluation on measures of athletic performance. For the other perspective, a long-term analysis can be relevant, mainly to verify the effects of training with the objective of reduce the BLD levels on the judo performance throughout a competition season (Bishop et al., 2021).

## **Conclusion**

In conclusion, the bilateral deficit is found in all the CMJ parameters (jump height, peak power, mean power, peak force and impulse) when judo athletes were evaluated. These parameters are correlated

(large to very large) to the performance of the SJFT, especially in different series, total throws and index. Also, the bilateral deficit of mean power parameter seems the best indicator of SJFT performance. Based on the results of this study, it is recommended that coaches assess the lower limb strength/ power BLD of judo athletes over the season using the unilateral/bilateral CMJ test to monitor the training effects. Moreover, the addition of unilateral exercises associated with the traditional bilateral-based training programs is suggested, as several unilaterally actions are usually performed by judo athletes (e.g., leg throwing techniques) and also bilaterally (e.g. support base for some techniques, such as hip and hand techniques groups).



## References

- Ascenzi, G., Ruscello, B., Filetti, C., Bonanno, D., Di Salvo, V., Nuñez, F. J., ... & Suarez-Arrones, L. (2020). Bilateral deficit and bilateral performance: Relationship with sprinting and change of direction in elite youth soccer players. *Sports*, 8(6), 82. <https://doi.org/10.3390/sports8060082>
- Bishop, C., Berney, J., Lake, J., Loturco, I., Blagrove, R., Turner, A., & Read, P. (2021). Bilateral deficit during jumping tasks: Relationship with speed and change of direction speed performance. *Journal of Strength & Conditioning Research*, 35(7), 1833-1840. <https://doi.org/10.1519/JSC.0000000000003075>
- Bishop, C., Abbott, W., Brashill, C., Read, P., Loturco, I., Beato, M., & Turner, A. N. (2021). Effects of pre-season strength training on bilateral and unilateral jump performance, and the bilateral deficit in premier league academy soccer players. *Professional Strength & Conditioning*.
- Bobbert, M. F., de Graaf, W. W., Jonk, J. N., & Casius, L. R. (2006). Explanation of the bilateral deficit in human vertical squat jumping. *Journal Of Applied Physiology*, 100(2), 493-499. <https://doi.org/10.1152/jappphysiol.00637.2005>
- Botton, C. E., Radaelli, R., Wilhelm, E. N., Rech, A., Brown, L. E., & Pinto, R. S. (2016). Neuromuscular adaptations to unilateral vs. bilateral strength training in women. *Journal Of Strength And Conditioning Research*, 30(7), 1924-1932. <https://doi.org/10.1519/JSC.0000000000001125>
- Bračič, M., Supej, M., Peharec, S., Bačić, P., & Čoh, M. (2010). An investigation of the influence of bilateral deficit on the counter-movement jump performance in elite sprinters. *Kinesiology*, 42(1), 73-81.
- Chaabene, H., Negra, Y., Bouguezzi, R., Capranica, L., Franchini, E., Prieske, O., ... & Granacher, U. (2018). Tests for the assessment of sport-specific performance in Olympic combat sports: a systematic review with practical recommendations. *Frontiers in physiology*, 9, 386. <https://doi.org/10.3389/fphys.2018.00386>
- Cohen, D. D., Burton, A., Wells, C., Taberner, M., Diaz, M. A., & Graham-Smith, P. (2020). Single v double leg countermovement jump tests; not half an apple. *Aspetar Sports Medicine Journal*, 9, 34-41.
- Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal Of Sports Physiology and Performance*, 3(2), 131-144. <https://doi.org/10.1123/ijsp.3.2.131>

- Dal Pupo, J., Ache-Dias, J., Kons, R. L., & Detanico, D. Are vertical jump height and power output correlated to physical performance in different sports? An allometric approach. *Human Movement*, 22(1). <http://dx.doi.org/10.5114/hm.2021.100014>
- Detanico, D., Dal Pupo, J., Franchini, E., & dos Santos, S. G. (2012). Relationship of aerobic and neuromuscular indexes with specific actions in judo. *Science & Sports*, 27(1), 16-22. <https://doi.org/10.1016/j.scispo.2011.01.010>
- Detanico, D., Dal Pupo, J., Franchini, E., & Dos Santos, S. G. (2015). Effects of successive judo matches on fatigue and muscle damage markers. *Journal of Strength & Conditioning Research*, 29(4), 1010-1016. <https://doi.org/10.1519/jsc.0000000000000746>
- Del Vecchio, F. B., Dimare, M., Franchini, E., & Schaun, G. Z. (2014). Physical fitness and maximum number of all-out hikidashi uchi-komi in judo practitioners. *Medicina Dello Sport*, 67, 383-396.
- Franchini, E., Vecchio, F. B. D., & Sterkowicz, S. (2009). A special judo fitness test classificatory table. *Archives of Budo*, 5, 127-129.
- Franchini, E., Del Vecchio, F. B., Matsushigue, K. A., & Artioli, G. G. (2011). Physiological profiles of elite judo athletes. *Sports Medicine*, 41(2), 147-166. <https://doi.org/10.2165/11538580-000000000-00000>
- Franchini, E., Artioli, G. G., & Brito, C. J. (2013). Judo combat: time-motion analysis and physiology. *International Journal Of Performance Analysis In Sport*, 13(3), 624-641. <https://doi.org/10.1080/24748668.2013.11868676>
- Franchini, E., Kons, R. L., Panissa, V. L. G., & Detanico, D. (2021). Assessment of the Anaerobic Speed Reserve during Specific High-Intensity Exercise in Judo Athletes. *Journal of Science in Sport and Exercise*, 1-9. <https://doi.org/10.1007/s42978-021-00119-z>
- Gheller, R. G., Dal Pupo, J., Ache-Dias, J., Detanico, D., Padulo, J., & dos Santos, S. G. (2015). Effect of different knee starting angles on intersegmental coordination and performance in vertical jumps. *Human Movement Science*, 42, 71-80. <https://doi.org/10.1016/j.humov.2015.04.010>
- Howard, J. D., & Enoka, R. M. (1991). Maximum bilateral contractions are modified by neurally mediated interlimb effects. *Journal of Applied Physiology*, 70(1), 306-316. <https://doi.org/10.1152/jappl.1991.70.1.306>

- Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine*, 30(1), 1-15. <https://doi.org/10.2165/00007256-200030010-00001>
- Hopkins, W. G. (2002). A scale of magnitudes for effect statistics. *A new view of statistics*, 502, 411.
- Janzen, C. L., Chilibeck, P. D., & Davison, K. S. (2006). The effect of unilateral and bilateral strength training on the bilateral deficit and lean tissue mass in post-menopausal women. *European Journal Of Applied Physiology*, 97(3), 253-260. <https://doi.org/10.1007/s00421-006-0165-1>
- Kons, R. L., Ache-Dias, J., & Detanico, D. (2017). Can physical tests predict the technical-tactical performance during official judo competitions?. *Archives of Budo Science of Martial Arts and Extreme Sports*, 13, 143-151.
- Kons, R. L., Dal Pupo, J., Ache-Dias, J., & Detanico, D. (2018). Female judo athletes' physical test performances are unrelated to technical–tactical competition skills. *Perceptual and Motor Skills*, 125(4), 802-816. <https://doi.org/10.1177/0031512518777586>
- Kons, R. L., Diefenthaler, F., Orssatto, L. B., Sakugawa, R. L., da Silva Junior, J. N., & Detanico, D. (2019). Relationship between lower limb asymmetry and judo-specific test performance. *Sport Sciences for Health*, 1-8. <https://doi.org/10.1007/s11332-019-00606-5>
- Kons, R. L., Orssatto, L. B. D. R., Sakugawa, R. L., da Silva Junior, J. N., Diefenthaler, F., & Detanico, D. (2020). Effects of stretch-shortening cycle fatigue protocol on lower limb asymmetry and muscle soreness in judo athletes. *Sports Biomechanics*, 1-16. <https://doi.org/10.1080/14763141.2020.1779335>
- Kons, R. L., Dal Pupo, J., Gheller, R. G., Costa, F. E., Rodrigues, M. M., Bishop, C., & Detanico, D. (2021a). Effects of successive judo matches on interlimb asymmetry and bilateral deficit. *Physical Therapy in Sport*, 47, 15-22. <https://doi.org/10.1016/j.ptsp.2020.10.007>
- Kons, R. L., Detanico, D., & Franchini, E. (2021b). Internal versus external focus of attention on high-intensity exercise performance in judo athletes. *Sport Sciences for Health*, 1-7. <https://doi.org/10.1007/s11332-020-00711-w>
- Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, 15(2), 155-163. <https://dx.doi.org/10.1016%2Fj.jcm.2016.02.012>
- Kozinc, Ž., & Šarabon, N. (2021). Bilateral deficit in countermovement jump and its association with change of direction performance in basketball and tennis players. *Sports Biomechanics*, 1-14. <https://doi.org/10.1080/14763141.2021.1942965>

- Linthorne, N. P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics*, 69(11), 1198-1204. <https://doi.org/0.1119/1.1397460>
- Lopes-Silva, J. P., Panissa, V. L. G., Julio, U. F., & Franchini, E. (2021). Influence of physical fitness on special judo fitness test performance: A multiple linear regression analysis. *Journal of Strength & Conditioning Research*, 35(6), 1732-1738. <https://doi.org/10.1519/jsc.0000000000002948>
- Magnus, C. R., & Farthing, J. P. (2008). Greater bilateral deficit in leg press than in handgrip exercise might be linked to differences in postural stability requirements. *Applied Physiology, Nutrition, and Metabolism*, 33(6), 1132-1139. <https://doi.org/10.1139/h08-101>
- Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength & Conditioning Research*, 18(3), 551-555. [https://doi.org/10.1519/1533-4287\(2004\)18%3C551:rafvos%3E2.0.co;2](https://doi.org/10.1519/1533-4287(2004)18%3C551:rafvos%3E2.0.co;2)
- Petroski, E. L., & Pires-Neto, C. S. (1996). Validation of anthropometric equations for estimating body density in men. *Brazilian Journal of Physical Activity and Health*, 1, 5–14. <https://doi.org/10.12820/rbafs.v.1n3p5-14>
- Rejc, E., Lazzer, S., Antonutto, G., Isola, M., & Di Prampero, P. E. (2010). Bilateral deficit and EMG activity during explosive lower limb contractions against different overloads. *European Journal Of Applied Physiology*, 108(1), 157-165. <https://doi.org/10.1007/s00421-009-1199-y>
- Siri, W. E. (1961). Body composition from fluid spaces and density: Analysis of methods. In J. Brozek & A. Henschel (Eds.), *Techniques for measuring body composition* (pp. 223–244). Washington, DC: National Academy of Sciences—National Research Council.
- Shiroma, S. A., Julio, U. F., & Franchini, E. (2019). Criterion validity, reliability, and usefulness of a judo-specific maximal aerobic power test. *International Journal of Sports Physiology and Performance*, 14(7), 987-993. <https://doi.org/10.1123/ijsp.2018-0813>
- Sogabe, A., Sterekowicz-Przybycien, K., Maehara, K., Sasaki, T., & Sterkowicz, S. (2015). Effect of preferred body stance on the performance of special judo fitness test in Japanese judo athletes. *Archives of Budo*, 11.
- Sterkowicz-Przybycień, K., Fukuda, D. H., & Franchini, E. (2019). Meta-analysis to determine normative values for the special judo fitness test in male athletes: 20+ years of sport-specific data and the lasting legacy of Stanisław Sterkowicz. *Sports*, 7(8), 194. <https://dx.doi.org/10.3390%2Fsports7080194>

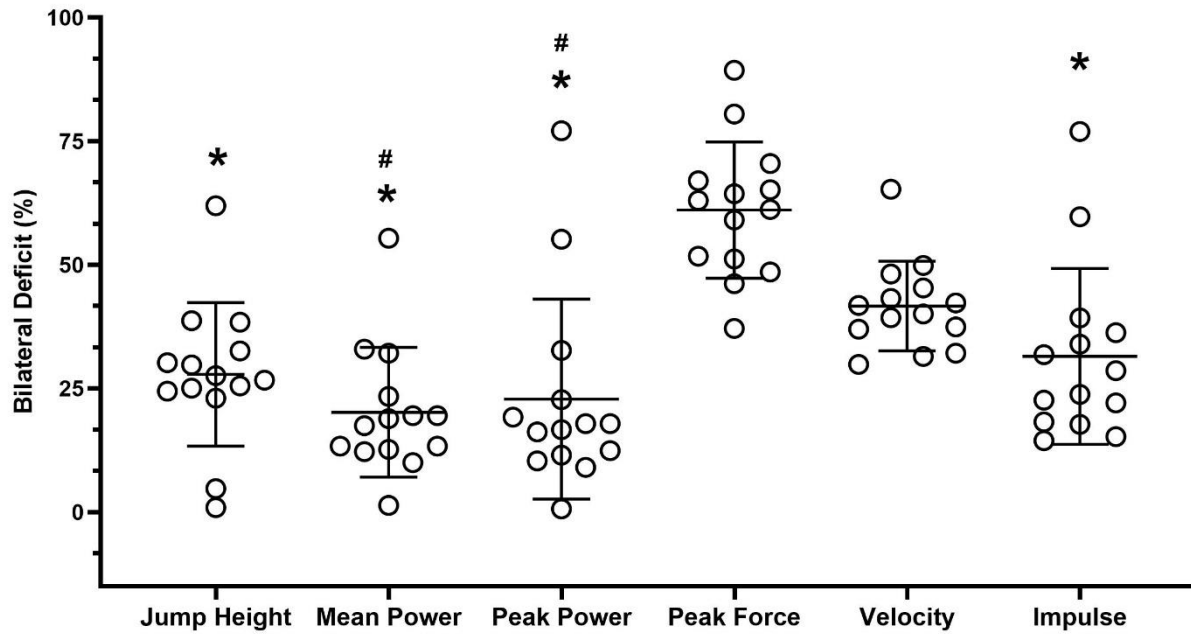
Sterkowicz, S., Zuchowicz, A., & Kubica, R. (1999). Levels of anaerobic and aerobic capacity indices and results for the special fitness test in judo competitors. *Journal of Human Kinetics*, 2(1), 115-135.

Turnes, T., Silva, B. A., Kons, R. L., & Detanico, D. (2019). Is bilateral deficit in handgrip strength associated with performance in specific judo tasks?. *Journal of Strength and Conditioning Research*, 27 1-12. <https://doi.org/10.1519/jsc.0000000000003441>

Zaggelidis, G., Lazaridis, S. N., Malkogiorgos, A., & Mavrovouniotis, F. (2012). Differences in vertical jumping performance between untrained males and advanced Greek judokas. *Archives of Budo*, 8, 87–90.

## Figure Legends

**Figure 1.** Bilateral deficit percentages for the countermovement jump parameters. \*difference for the peak force BLD, # difference for velocity BLD.



**Table 1.** Mean  $\pm$ SD and reliability values of single leg (dominant and non-dominant) and bilateral countermovement jump (CMJ) parameters.

<b>CMJ parameters</b>	<b>Mean <math>\pm</math> SD</b>	<b>ICC (95% CI)</b>	<b>TE (95% CI)</b>
Jump Height <sup>BL</sup> (cm)	38.5 $\pm$ 12.1	0.99 (0.96 – 1.00)	1.43 (1.07 – 2.15)
Jump Height <sup>D</sup> (cm)	29.0 $\pm$ 3.8	0.93 (0.86 – 0.98)	5.8 (4.60 – 8.91)
Jump Height <sup>ND</sup> (cm)	28.7 $\pm$ 4.1	0.92 (0.83 – 0.98)	9.40 (7.41 – 14.5)
Mean Power <sup>BL</sup> (W)	1741.7 $\pm$ 647.3	0.99 (0.98 – 1.00)	2.21 (1.36 – 6.59)
Mean Power <sup>D</sup> (W)	1162.2 $\pm$ 163.6	0.95 (0.87 – 0.98)	4.66 (3.67 – 7.08)
Mean Power <sup>ND</sup> (W)	1303.7 $\pm$ 287.0	0.96 (0.92 – 0.99)	8.80 (6.90 – 13.5)
Peak Power <sup>BL</sup> (W)	3343.2 $\pm$ 1252.6	0.99 (0.98 – 1.00)	2.52 (1.55 – 7.54)
Peak Power <sup>D</sup> (W)	2209.9 $\pm$ 316.0	0.95 (0.89 – 0.98)	4.89 (3.85 – 7.43)
Peak Power <sup>ND</sup> (W)	2487.5 $\pm$ 550.6	0.96 (0.90 – 0.99)	9.29 (7.27 – 14.2)
Peak Force <sup>BL</sup> (N)	1568.2 $\pm$ 537.8	0.97 (0.91 – 0.99)	3.27 (2.01 – 9.84)
Peak Force <sup>D</sup> (N)	1272.1 $\pm$ 227.4	0.98(0.95 – 0.99)	3.32 (2.61 – 5.02)
Peak Force <sup>ND</sup> (N)	1141.2 $\pm$ 251.7	0.97 (0.93 – 0.99)	4.19 (3.30 – 6.35)
Velocity <sup>BL</sup> (m·s <sup>-1</sup> )	2.59 $\pm$ 0.26	0.97 (0.92 – 0.99)	1.17 (0.72 – 3.45)
Velocity <sup>D</sup> (m·s <sup>-1</sup> )	1.88 $\pm$ 0.18	0.97 (0.94 – 0.99)	2.61 (2.06 – 3.95)
Velocity <sup>ND</sup> (m·s <sup>-1</sup> )	1.92 $\pm$ 0.35	0.97 (0.94 – 0.99)	6.26 (4.91 – 9.54)
Impulse <sup>BL</sup> (N·s)	274.3 $\pm$ 52.1	0.97 (0.90 – 0.99)	8.48 (6.41 – 12.8)
Impulse <sup>D</sup> (N·s)	183.7 $\pm$ 25.5	0.93 (0.83 – 0.97)	8.45 (6.62 – 12.9)
Impulse <sup>ND</sup> (N·s)	192.4 $\pm$ 38.3	0.89 (0.72 – 0.96)	8.18 (6.42 – 12.5)

ICC = intraclass correlation coefficient; TE = typical error; BL = bilateral limb; D = dominant limb; ND = non-dominant limb;

**Table 2.** Descriptive values of judo-specific tests – Maximal Sprint Speed Judo Test, Maximal Aerobic Speed Judo Test and Special Judo Fitness Test in judo athletes.

<b>Judo-Specific Tests</b>	<b>Mean <math>\pm</math> SD</b>	<b>Minimum</b>	<b>Maximum</b>
Maximal Sprint Speed Judo Test (s)	3.41 $\pm$ 0.61	2.22	4.31
Maximal Aerobic Speed Judo Test (n)	52 $\pm$ 6	43	62
<b>Special Judo Fitness Test</b>			
Throws A (n)	5 $\pm$ 0	4	6
Throws B (n)	10 $\pm$ 1	9	12
Throws C (n)	11 $\pm$ 0	10	13
Total throws (n)	27 $\pm$ 1	25	30
Heart Rate final (bpm)	174 $\pm$ 9	159	159
Heart Rate 1 min after (bpm)	144 $\pm$ 14	120	186
Index	11.4 $\pm$ 1.10	9.8	14.2



**Table 3.** Correlation between lower limb percentage of bilateral deficit in countermovement jump (CMJ) variables and judo-specific performance tests.

Bilateral Deficit	MSSJT	MASJT	SJFT <sub>A</sub>	SJFT <sub>B</sub>	SJFT <sub>C</sub>	SJFT <sub>TT</sub>	HR <sub>FINAL</sub>	HR <sub>1MIN</sub>	SJFT <sub>INDEX</sub>
Jump Height	0.02	-0.32	-0.39	-0.44	-0.14	-0.61*	0.08	0.12	0.38
Mean Power	-0.03	-0.06	-0.45	-0.74*	-0.18	-0.85*	0.28	0.36	0.71*
Peak Power	-0.06	-0.04	-0.14	-0.07	-0.29	-0.53*	0.32	0.14	0.34
Peak Force	0.47	-0.23	-0.60*	-0.40	-0.14	-0.69*	0.21	0.37	0.59*
Peak Velocity	-0.18	0.30	-0.26	-0.59*	-0.12	-0.73*	0.33	0.28	0.63*
Impulse	-0.18	0.06	-0.23	-0.55*	-0.13	-0.61*	0.34	0.40	0.63*

MSSJT = Maximal sprint speed judo test; MASJT = Maximal aerobic speed judo test; SJFT = Special Judo Fitness Test; HR<sub>FINAL</sub> = Heart rate immediately after; HR<sub>1MIN</sub> = Heart rate after 1 min. \* p<0.05.