©Journal of Sports Science and Medicine (2018) **17**, 465-474
http://www.jssm.org

Research article

Validation of A New Judo-Specific Ergometer System in Male Elite and Sub-Elite Athletes

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Abstract
Our experimental approach included two studies to determine discriminative validity and test-retest reliability (study 1) as well as ecological validity (study 2) of a judo ergometer system while performing judo-specific movements. Sixteen elite (age: 23 ± 3 years) and 11 sub-elite (age: 16 ± 1 years) athletes participated in study 1 and 14 male sub-elite judo athletes participated in study 2. Discriminative validity and test-retest reliability of sport-specific parameters (mechanical work, maximal force) were assessed during pulling movements with and without *tsukuri* (*kuzushi*). Ecological validity of muscle activity was determined by performing pulling movements using the ergometer without *tsukuri* and during the same movements against an opponent. In both conditions, electromyographic activity of trunk (e.g., m. erector spinae) and upper limb muscles (e.g., m. biceps brachii) were assessed separately for the lifting and pulling arm. Elite athletes showed mostly better mechanical work, maximal force, and power ($0.12 \leq d \leq 1.80$) compared with sub-elite athletes. The receiver operating characteristic analysis revealed acceptable validity of the JERGo© system to discriminate athletes of different performance levels predominantly during *kuzushi* without *tsukuri* (area under the curve = 0.27-0.90). Moreover, small-to-medium discriminative validity was found to detect meaningful performance changes for mechanical work and maximal force. The JERGo© system showed small-to-high relative (ICC = 0.37-0.92) and absolute reliability (SEM = 10.8-18.8%). Finally, our analyses revealed acceptable correlations (r = 0.41-0.88) between muscle activity during *kuzushi* performed with the JERGo© system compared with a judo opponent. Our findings indicate that the JERGo© system is a valid and reliable test instrument for the assessment and training of judo-specific pulling kinetics particularly during *kuzushi* movement without *tsukuri*.

Key words: Judo-specific pulling movement, work, force, muscle activity, reliability.

Introduction

A systematic performance analysis of the judo competitions during the 2016 Summer Olympic Games in Rio de Janeiro revealed a more offensive combat behavior and a high action density as well as an increased effectiveness of individual techniques (Heinisch et al., 2017). In this regard, it has been shown that defeated judo players displayed less proficient throwing techniques compared with the winners. This finding was previously substantiated by a deficient judo-specific pulling movement during the onset of the throwing technique in defeated judo players who were not able to sufficiently perturb balance of their opponent (*uke*) (Heinisch et al., 2012). Of note, the preparatory phase (i.e., *kuzushi*) of a judo maneuver has been deemed critical to perform a successful judo throwing technique (e.g., *morote-seoi-nage, tai-otoshi*) (Blais et al., 2007a; Gutierrez et al., 2009; Imamura et al., 2006). More specifically, *kuzushi* represents the first and critical phase of a throwing technique with the goal to perturb an opponent's balance (Gomes et al., 2017). In this regard, *kuzushi* is a typical movement that is performed several times during judo-specific training to increase the effectiveness of judo throwing techniques in competition (Franchini et al., 2013; 2014).

In terms of *kuzushi* performance, high levels of muscle strength and particularly muscle power are important determinants for the successful performance of throwing techniques (Callister et al., 1991; Drid et al., 2015). Furthermore, powerful *kuzushi* movements have the potential to limit *uke's* time to initiate a defensive maneuver and to counteract balance-threatening situations (Imamura et al., 2007; Imamura et al., 2006). Indeed, studies revealed that maximal force and isokinetic torque production of upper limb muscles (e.g., elbow flexors and extensors) were significantly associated with judo-specific performance measures and/or success during judo competitions (Callister et al., 1991; Drid et al., 2015). However, there are only a few tools and devices available for the standardized assessment of sport-specific kinetics during *kuzushi* movements.

In this regard, Blais and colleagues (Blais et al., 2007b) introduced a judo-specific apparatus to assess *kuzushi* performance during dynamic change of position (*tsukuri*). Ecological validity was examined using force sensors for the lifting and pulling arm. Significantly different pulling forces were found between the two test exercises (judo-specific training machine vs. *uke*). The same authors explained this finding with differences in the resistive load when working with the apparatus compared to the opponent. Of note, the judo-specific apparatus in the studies of Blais et al. (2006; 2007a; 2007b) is a stationary device and only pulling masses can be executed during judo-throwing techniques (e.g., *morote-seoi-nage*).

A new judo ergometer system (JERGo©, Institut für Forschung und Entwicklung von Sportgeräten, Berlin, Germany) has been introduced as an alternative approach for the assessment of judo-specific kinetics. The JERGo© system immediately provides independent knowledge of

Received: 13 April 2018 / Accepted: 11 July 2018 / Published (online): 14 August 2018

result (kinetic parameter) and performance (force displacement characteristics) during *kuzushi* with and without *tsukuri* for the pulling and the lifting arm, respectively. Further, the JERGo© system is a mobile system and easy-to-administer and install in regular judo gyms (*dojos*). Moreover, the apparatus' resistance can be individually adjusted according to each athlete's weight category. Thus, *kuzushi* performance with and without *tsukuri* cannot only be tested but also trained using the JERGo© system (Helm et al., 2018).

An important pre-requisite for the application of the JERGo© system during testing and training is that it provides valid and reliable data regarding the performance level (discriminative validity). Thus, two studies using the JERGo© system were designed to determine discriminative validity and test-retest reliability as well as ecological validity of judo-specific performance measures in male elite and sub-elite judo athletes. With reference to the study of Blais et al. (2007b) and because of the technical possibility to adjust the loads in accordance with the athletes' weight category, we expected acceptable discriminative validity and test-retest reliability as well as ecological validity of judo-specific pulling kinetics using the JERGo© system.

Methods

Participants

The main participant's characteristics are summarized in Table 1. In both experiments (study 1 and 2), at least two athletes from each weight category (-60 kg, -66 kg, -73 kg, -81 kg, -90 kg, -100 kg, +100 kg) were tested. Local ethical permission was provided and both studies were conducted in accordance with the latest version of the Declaration of Helsinki.

Procedures

Our experimental approach included two studies to determine discriminative validity and test-retest reliability (study 1) as well as ecological validity (study 2) of a judo ergometer (JERGo©) system while performing judo-specific movements. Both experiments used a standardized general warm-up comprising 60 seconds rope-skipping and a judo-specific warm-up consisting of 10 submaximal and 3 maximal *kuzushi* movements with and without *tsukuri* using the JERGo© system and *uke*. A 3 seconds rest was provided between trials and 5 minutes were considered between each test condition. Discriminative validity and test-retest reliability of sport-specific parameters (mechanical work, maximal force, power) were assessed during 10 maximal *kuzushi* movements with (Figure 1a) and without (Figure 1b) *tsukuri* using the JERGo© system. The first and the last trial were removed and the best out of 8 trials (2nd to 9th) was used for further analysis. To examine test-retest reliability, measurements were repeated within a one-week interval (five-to-seven days).

Ecological validity of trunk and upper limb muscle activity was determined during 6 maximal *kuzushi* movements without *tsukuri* using either the JERGo© system (Figure 2a) or *uke* (Figure 2b). The first trial was removed and the average of 5 trials was used for further analysis. The testing of the two conditions (study 1: *kuzushi* with or without *tsukuri*, study 2: JERGo© system or *uke*) were carried out in randomized order. Rest between trials was 3 seconds and rest between two test conditions amounted to 5 minutes. All athletes were measured while performing the standardized judo technique *morote-seoi-nage*.

Table 1. Characteristics of studies participants and differences in the anthropometric and training characteristics between male elite and sub-elite judo athletes.

	Study 1			Study 2
	Elite athletes (n = 16)	Sub-elite athletes (n = 11)	*p*-value (*d*)	Sub-elite athletes (n = 14)
Performance level	international	national		national
Age (years)	23.4 ± 3.0	15.9 ± 1.1	<.001 (3.08)	17.9 ± .7
Body mass (kg)	90.0 ± 21.9	73.6 ± 12.6	.035 (.87)	79.6 ± 15.2
Body height (m)	1.79 ± .08	1.7 ± .08	.881 (.06)	1.79 ± .09
Training experience (years)	20.8 ± .9	8.5 ± 2.4	<.001 (6.77)	10.6 ± 1.7
Training volume per week (hours)	21.0 ± 1.4	15.4 ± 1.1	<.001 (4.14)	16.6 ± 2.0

Data was shown as mean ± standard deviation (mean ± *SD*). *d* = effect size.

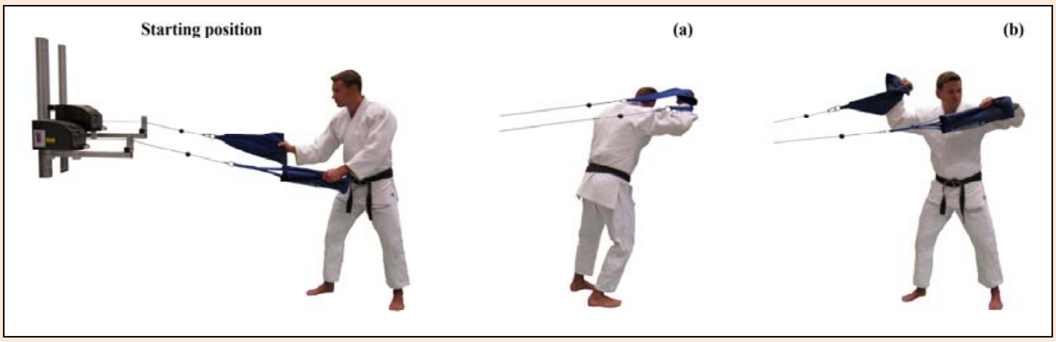

Figure 1. Setup for the assessment of (a) *kuzushi with tsukuri* and (b) *kuzushi* without *tsukuri* at the judo ergometer (JERGo©) system.

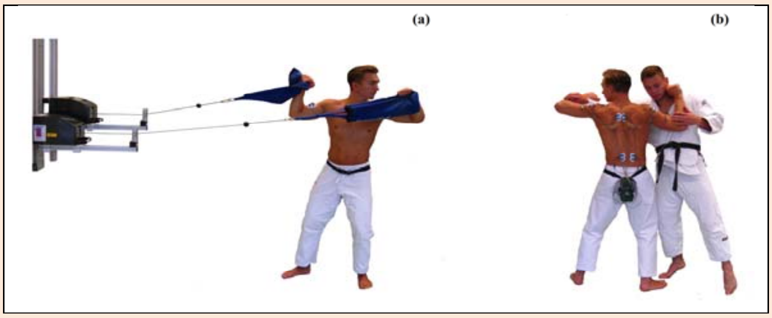

Figure 2. **Electromyographic analysis of *kuzushi* without *tsukuri* using (a) the judo ergometer (JERGo©) system and (b) *uke*. Activity of the m. deltoideus, the m. biceps brachii, the m. erector spinae, and the m. trapezius were separately recorded for the lifting and the pulling arm.**

Figure 3. **Judo ergometer (JERGo©) system with real time display for judo-specific performances (i.e., mechanical work, maximal force, power) and force displacement characteristics for the pulling (left display) and the lifting (right display) arm during repeated *kuzushi* movements.**

Testing with the JERGo© system

The testing apparatus consists of a wall bracket, two mobile JERGo© systems (lifting and pulling arm) and a combat judo mat of four square meters (Figure 3). The rotor of the eddy current brake is connected to a winding drum via a shaft. The pulling cable is rolled up on the shaft and contains judo-specific grips (see Figure 3). The shaft is rigidly connected to the rotor of the eddy current brake and thus the force transmission takes place in only one direction of rotation. During a pulling movement, forces are transmitted through a free wheel of the shaft onto the rotor of the eddy current brake. For the JERGo© system, lifting and pulling arm grips were manufactured according to a judo kimono (*Adidas* company, see Figure 3). This allows the athletes to perform a judo-specific sleeve-reverse grip. The JERGo© software (JERGo2000 V 5.1) was developed using LabView 8.6. Data transfer from the sensor is controlled by a microcontroller (AT Mega 128). In addition, the controller adopts the pulse width control for the eddy current brake and the communication with the PC (via USB). Data (e.g., athlete, testing place, testing date) and results were recorded using a custom-made software. Before the JERGo© system is ready for testing, a calibration is carried out for zero-point transfer. The individual adjustment of the eddy current brakes (height of lifting and pulling arm, brake resistance) is interlocked by the athletes' weight category and body height as well as the preferred judo technique. Judo-specific kinetics (mechanical work [the amount of energy transferred by a force], maximal force [peak force of the time-force curve], power [the rate of doing mechanical work]) as well as force displacement characteristics for the pulling and lifting arm were analyzed and displayed on a laptop. Relative values (normalized to body mass) were used to determine discriminative validity and absolute values were used to calculate test-retest reliability. Figure 3 shows the JERGo© system with an online recording screenshot for *kuzushi* without *tsukuri*. Resistance of the two eddy current brakes was regulated according to each athlete's weight category using seven brake levels (-60 kg = 500 N, -66 kg = 600 N, -73 kg = 700 N, -81 kg = 800 N, -90 kg = 900 N, -100 kg = 1,000 N, +100 kg = 1,000 N). In addition, a grading of the brake load was conducted at pull-out length (waypoint [WP] 1: 100% [≥ 0 cm], WP2: 80% [≥ 20 cm], WP3: 50% [≥ 40 cm], return

[RT]: 50%). One-hundred percent resistance at WP1 was defined by the respective weight category (i.e., -100 kg = 1,000 N and -60 kg = 500 N at WP1). The optimal resistance by weight category and at pull-out length was determined in pilot studies with the male German judo national squad. The height of the eddy current brake was adjusted for the lifting hand at athletes' shoulder and for the pulling arm at athletes' elbow.

Testing with *uke*

Each participating athlete was allowed to select his preferred *uke* according to *tori*'s weight category and body height. When executing *kuzushi* without *tsukuri*, *uke* did not actively resist and promote the pulling movement in regular judo-specific posture. In other words, *uke* was passive.

Assessment of muscle activity

During *kuzushi* without *tsukuri* (Figures 2a-b), electromyographic (EMG) activity of the m. deltoideus (pars acromialis), the m. biceps brachii, the m. erector spinae (pars lumbalis), and the m. trapezius (pars transversa) was measured using circular bipolar surface electrodes (Ambu®, type: Blue Sensor P-00-S/50, Ag/AgCl, diameter: 13 mm, center-to-center distance: 25 mm, Ballerup, Denmark). Electrodes were positioned on the muscle bellies according to the European recommendations for surface electromyography (Hermens et al., 1999). The EMG signals were amplified and telemetrically recorded (TeleMyo 2400 G2, Noraxon®, Scottsdale, AZ, USA) at a sampling frequency of 1,500 Hz. Subsequently, signals were saved and further processed using MyoReseach XP Master Edition-Software (Version 1.08.17, Noraxon®, Scottsdale, AZ, USA). EMG signals were not normalized because testing was conducted during one test session in a within but not between-subject design. For later offline analysis, electrical heart muscle activity artifacts were removed from the trunk muscle signals (Prieske et al., 2013). Afterward, EMG signals were smoothed using a digital bandpass (high-pass: 10 Hz, low-pass: 750 Hz) and full wave rectified filter. During the performance with the JERGo© system as well as with *uke*, EMG data was synchronized using a 2D accelerometer (Noraxon®, Scottsdale, AZ, USA) attached to the wrist of the pulling arm. A moving root mean square filter was applied to process the acceleration signal with a time constant of 50 ms. Onset of muscle activity was set at 20% of the maximal acceleration signal. For further analysis, the mean amplitude voltage (MAV) was taken separately for the lifting and pulling arm for time intervals of 0-30 ms, 0-50 ms, 0-100 ms, and 0-200 ms. These time intervals provide information on muscle activation patterns during high velocity (explosive-type) movements (Prieske et al., 2014).

Statistical analysis

Data were unimodally distributed and thus presented as mean values and standard deviations (*SD*). Data were tested for normal distribution using the Shapiro-Wilk test. Discriminative validity of the JERGo© system was established from analysis of variance (ANOVA) to compare performances of elite and sub-elite groups. Effect size (*d*) was determined and rated as follow: "small" $d < 0.50$, "moderate" $0.50 \leq d < 0.80$, and "large" $d \geq 0.80$ (Cohen, 1988). Additionally, the receiver operator characteristic (ROC) curve analysis was conducted. According to Deyo and Center (1986), an area under the ROC curve (AUC) > 0.70 is deemed to indicate "good" discriminative validity of the JERGo© system. Relative and absolute reliability were assessed using the intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) expressed as coefficient of variation (CV), respectively. According to Fleiss (1986), ICC > 0.75 are classified as "excellent", "fair-to-good" if between 0.40 and 0.75, and "poor" if < 0.40. Of note, CV values of ≤15% are classified as satisfactory (Stokes, 1985). Practical relevance of the JERGo© system was assessed by comparing the smallest worthwhile change (SWC) and the SEM. The SWC was assumed by multiplying the between-subjects *SD* by 0.2 ($SWC_{0.2}$) indicating the typical small effect, 0.6 ($SWC_{0.6}$) a moderate effect, and 1.2 ($SWC_{1.2}$) a large effect (Hopkins et al., 2009). The ability of the test to detect a change was rated as "good", "OK", or "marginal" when the SEM was below, similar, or higher than the SWC, respectively (Liow and Hopkins, 2003). The minimal detectable change ($MDC_{95\%}$) of the JERGo© system was determined as $MDC_{95\%} = SEM \times 1.96 \times \sqrt{2}$ (Haley and Fragala-Pinkham, 2006). Ecological validity was quantitatively assessed with the Pearson correlation coefficient (*r*). The magnitude of effects was qualitatively rated as "small" $r < 0.7$, "moderate" $0.7 \leq r < 0.9$, and "large" $r \geq 0.9$ (Vincent and Weir, 2012). Further, Bland-Altman plots were provided to identify the magnitude of agreement between the two conditions (i.e., *kuzushi* without *tsukuri* at the JERGo© system and with *uke*). Here, the differences in muscle activities between conditions were plotted against the mean of the respective measurements (Bland and Altman, 1986). It was previously recommended that 95% of the data points should lie within the mean ± 1.96 *SD* (limits of agreement [LOA]) of the differences between conditions (Bland and Altman, 1986). Lastly, a repeated measures ANOVA was used to compare muscle activity during *kuzushi* without *tsukuri* performed with the judo ergometer (JERGo©) system and with *uke*. The statistical significance level was set at $p < 0.05$. All analyses were performed using the Statistical Package for Social Sciences (IBM® SPSS® Statistics 23).

Results

Discriminative validity of judo-specific pulling kinetics

Table 2 shows absolute and relative judo-specific pulling kinetics for elite and sub-elite athletes. For *kuzushi* without *tsukuri*, elite compared to sub-elite athletes achieved significant and "large" judo-specific pulling kinetics in mechanical work ($p < 0.05$; $1.09 \leq d \leq 1.80$) and in power ($p \leq 0.05$; $0.88 \leq d \leq 0.93$). However, non-significant between-group differences were observed for maximal force ($p > 0.05$; $0.50 \leq d \leq 0.52$). The discriminative validity showed "excellent" AUC values for mechanical work ($0.77 \leq AUC \leq 0.90$) and power ($AUC = 0.71$), and "poor to fair" for maximal force ($0.27 \leq AUC \leq 0.66$).

During *kuzushi* with *tsukuri*, elite compared to sub-elite athletes showed non-significant but "moderate-to-large" effects for mechanical work ($p > 0.05$; $0.65 \leq d \leq 0.90$), "small" for maximal force ($p > 0.05$; $0.24 \leq d \leq$

0.45), and "small-to-large" for power ($p > 0.05$; $0.12 \leq d \leq 0.84$). The respective AUC values indicated "fair-to-excellent" values in mechanical work ($0.67 \leq AUC \leq 0.73$) and in power ($0.45 \leq AUC \leq 0.71$), as well as "fair" in maximal force ($0.53 \leq AUC \leq 0.59$).

Test-retest reliability of judo-specific pulling kinetics

Table 3 presents ICC, SEM, and SWC values for test-retest reliability of both test conditions and arms. Results indicated "excellent" ICC values in mechanical work ($0.76 \leq ICC \leq 0.92$) and "poor-to-excellent" ICC values in maximal force ($0.37 \leq ICC \leq 0.80$). However, our test-retest analysis indicated "poor" to "fair to good" reliability for power ($0.19 \leq ICC \leq 0.51$). In addition, SEM in the form of CV values ranged from 10.8 to 18.8% for mechanical work and maximal force, and from 24.2 to 47.1% for power, irrespective of the examined arm and test condition. Further, the capacity to detect changes was predominately good for $SWC_{0.6}$ and $SWC_{1.2}$, irrespective of the analyzed arm and test condition. However, a marginal capacity to detect changes was found for $SWC_{0.2}$. Finally, the $MDC_{95\%}$ values ranged from 42.9 to 62.1 Nm for mechanical work, from 129.3 to 164.9 N for maximal force, and from 160.7 to 234.3 W for power, irrespective of the examined arm and test condition.

Table 2. Discriminative validity for the assessment of judo-specific performances between male elite and sub-elite judo athletes.

	All (n = 27)	Elite (n = 16)	Sub-elite (n =11)	*p*-value (*d*)	AUC
		Kuzushi without tsukuri			
W_{PA} (Nm)	188.9 ± 69.5	238.2 ± 46.4	130.7 ± 40.5	.001 (1.80)	.90
nW_{PA} (Nm/kg)	2.3 ± 0.7	2.6 ± 0.4	1.8 ± 0.5		
W_{LA} (Nm)	136.5 ± 48.9	165.6 ± 31.7	102.1 ± 43.6		
nW_{LA} (Nm/kg)	1.6 ± 0.5	1.8 ± 0.4	1.4± 0.5	.013 (1.09)	.77
$Fpeak_{PA}$ (N)	402.5 ± 126.2	453.2 ± 122.1	342.7 ± 107.0		
$nFpeak_{PA}$ (N/kg)	4.8 ± 1.3	5.2 ± 1.4	4.5 ±1.3	.198 (.52)	.66
$Fpeak_{LA}$ (N)	283.3 ± 69.6	298.4 ± 68.6	265.5 ± 69.7		
$nFpeak_{LA}$ (N/kg)	3.4 ± 0.8	3.2 ± 0.7	3.6 ± 0.9	.181 (.50)	.27
P_{PA} (W)	314.2 ± 105.3	420.9 ± 49.1	245.5 ± 72.7		
nP_{PA} (W/kg)	3.6 ± 1.0	3.9 ± 1.0	3.1 ± 0.8	.050 (.88)	.71
P_{LA} (W)	163.9 ± 97.9	246.0 ± 66.3	138.1 ± 82.3		
nP_{LA} (W/kg)	2.4 ± 0.7	2.7 ± 0.6	2.1 ± 0.7	.041 (.93)	.71
		Kuzushi with tsukuri			
W_{PA} (Nm)	134.9 ± 53.5	164.5 ± 50.0	99.9 ± 33.1	.129 (.65)	.67
nW_{PA} (Nm/kg)	(1.6 ± 0.6)	(1.8 ± 0.7)	(1.4 ± 0.5)		
W_{LA} (Nm)	107.7 ± 46.0	128.7 ± 42.6	82.9 ± 37.8	.065 (.90)	.73
nW_{LA} (Nm/kg)	(1.4 ± 0.6)	(1.6 ± 0.6)	(1.1 ± 0.5)		
$Fpeak_{PA}$ (N)	368.3 ± 136.1	423.7 ± 146.6	302.8 ± 90.2	.598 (.24)	.53
$nFpeak_{PA}$ (N/kg)	(4.5 ± 1.7)	(4.7 ± 2.0)	(4.3 ± 1.2)		
$Fpeak_{LA}$ (N)	236.5 ± 90.2	261.4 ± 74.0	207.1 ± 102.0	.447 (.45)	.59
$nFpeak_{LA}$ (N/kg)	(2.9 ± 1.3)	(3.2 ± 1.6)	(2.6 ± 0.9)		
P_{PA} (W)	141.8 ± 62.2	177.3 ± 48.5	140.9 ± 62.6	.743 (.12)	.45
nP_{PA} (W/kg)	(1.7 ± 0.8)	(1.7 ± 0.9)	(1.8 ± 0.7)		
P_{LA} (W)	134.3 ± 71.3	193.4 ± 72.3	95.8 ± 50.4	.086 (.84)	.71
nP_{LA} (W/kg)	(1.6 ± 0.8)	(1.8 ± 0.8)	(1.2 ± 0.6)		

Absolute and body mass normalized data was shown as mean ± standard deviation (mean ± *SD*). Differences between elite and sub-elite athletes were calculated using body mass normalized data for the first assessment. *d* = effect size, AUC = area under the receiver operating characteristics curve, W = mechanical work, Fpeak = maximal force, P = power, PA = pulling arm, LA = lifting arm, n = Body mass normalized data.

Table 3. Test-retest reliability for the assessment of judo-specific performances in male elite and sub-elite judo athletes.

	ICC (95% CI)	SEM	SEM (%)	$SWC_{0.2}$	$SWC_{0.6}$	$SWC_{1.2}$	$MDC_{95\%}$
			Kuzushi without tsukuri				
W_{PA} (Nm)	.87** (.70-.95)	22.2	10.8	13.5	40.6	81.2	61.5
W_{LA} (Nm)	.76** (.49-.90)	22.4	14.7	8.7	26.0	52.0	62.1
$Fpeak_{PA}$ (N)	.75** (.47-.89)	59.5	13.7	25.0	75.1	150.3	164.9
$Fpeak_{LA}$ (N)	.37* (−.07-.69)	48.9	16.6	12.5	37.6	75.1	135.6
P_{PA} (W)	.51* (.10-.77)	77.2	24.2	21.6	64.8	129.6	213.9
P_{LA} (W)	.19 (−.27-.58)	84.5	42.6	20.1	60.3	120.5	234.3
Kuzushi with tsukuri							
W_{PA} (Nm)	.76** (.49-.90)	20.3	14.8	8.7	26.1	52.1	56.2
W_{LA} (Nm)	.92** (.80-.97)	15.5	12.7	10.4	31.3	62.6	42.9
$Fpeak_{PA}$ (N)	.78** (.52-.91)	59.1	16.1	24.9	74.6	149.3	163.9
$Fpeak_{LA}$ (N)	.80** (.56-.92)	46.7	18.8	23.2	69.6	139.2	129.3
P_{PA} (W)	.32 (-.13-.66)	58.0	37.4	12.8	38.3	76.6	160.7
P_{LA} (W)	.32 (-.13-.66)	63.8	47.1	14.6	43.9	87.7	176.9

ICC = intraclass correlation coefficient, CI = confidence interval, SEM = standard error of measurement, SWC = smallest worthwhile change, $MDC_{95\%}$ = minimal detectable change, W = work, Fpeak = maximal force, P = power, PA = pulling arm, LA = lifting arm, *$p < 0.05$, **$p < 0.01$.

Ecological validity of muscle activity during a judo-specific pulling movement

Results for ecological validity of muscle activities during *kuzushi* movements without *tsukuri* using the JERGo© system compared to *uke* are illustrated in Table 4 and 5. The analysis revealed significant "moderate" r values for the m. erector spinae ($0.79 \leq r \leq 0.88$), significant "small-to-moderate" correlations for the m. deltoideus and m. biceps brachii ($0.60 \leq r \leq 0.82$), irrespective of the examined arm. Concerning the m. trapezius, the results yielded significant "moderate" r values for the pulling arm ($0.70 \leq r \leq 0.71$) and non-significant "small" correlations for the lifting arm ($0.41 \leq r \leq 0.53$).

Further, significant differences ($p < 0.05$) were found for the pulling arm for the m. deltoideus for all time intervals (0-30 ms, 0-50 ms, 0-100 ms, 0-200 ms), biceps brachii (0-50 ms, 0-100 ms, 0-200 ms) and m. trapezius (0-30 ms, 0-50 ms). Concerning the lifting arm, significant differences ($p < 0.05$) were observed for the m. deltoideus for all time intervals (0-30 ms, 0-50 ms, 0-100 ms, 0-200 ms) and for the m. erector spinae (0-30 ms, 0-50 ms, 0-100 ms) (Table 5).

Irrespective of the analyzed muscle, arm, and time interval, Bland-Altman analyses indicated zero to two out of 14 data points (≤ 14.3%) lying outside of the LOAs. An example of a Bland-Altman plot for the time interval 0-100 ms of the pulling arm (m. biceps brachii) is presented in Figure 4. Large systematic errors (~100 µV) were identified in all time intervals for the m. trapezius of the lifting arm. Erroneous data were also observed for longer time intervals (0-100 ms, 0-200 ms) of the lifting arm (m. biceps brachii, m. deltoideus, Table 4). In addition, lower variances with respect to the LOAs were obtained for the short (0-30, 0-50 ms) compared to the long (0-100 ms, 0-200 ms) time intervals.

Table 4. **Ecological validity of muscle activity during *kuzushi without tsukuri* performed with the judo ergometer (JERGo©) system and with *uke*.**

		Pulling arm		Lifting arm	
		r	**LOA**	***r***	**LOA**
M. deltoideus	0-30 ms	.60*	−154.0 ± 141.7	.79**	−46.5 ± 59.2
	0-50 ms	.61*	2.4 ± 107.4	.68**	−61.5 ± 81.5
	0-100 ms	.69*	−148.0 ± 134.6	.62*	−101.7 ± 129.7
	0-200 ms	.62*	−124.9 ± 163.5	.69**	−134.5 ± 174.6
M. biceps brachii	0-30 ms	.76*	23.5 ± 62.1	.75**	91.5 ± 199.2
	0-50 ms	.75**	53.7 ± 82.6	.79**	122.0 ± 213.5
	0-100 ms	.60*	118.5 ± 141.7	.82**	96.6 ± 234.5
	0-200 ms	.70**	186.3 ± 146.9	.81**	64.7 ± 238.7
M. erector spinae	0-30 ms	.85**	13.6 ± 76.2	.88**	−40.9 ± 40.1
	0-50 ms	.85**	6.4 ± 78.6	.87**	171.3 ± 123.1
	0-100 ms	.85**	8.1 ± 72.9	.86**	−35.8 ± 40.8
	0-200 ms	.82**	35.1 ± 79.9	.79**	−2.4 ± 39.6
M. trapezius	0-30 ms	.71**	−142.0 ± 201.5	.45	50.7 ± 153.4
	0-50 ms	.71**	−131.6 ± 219.0	.41	30.1 ± 196.3
	0-100 ms	.70**	−116.8 ± 225.9	.41	−40.7 ± 230.3
	0-200 ms	.70**	−133.0 ± 431.6	.53	−99.2 ± 230.0

r = Pearson correlation coefficient, LOA = limits of agreement, $^{*}p < 0.05$, $^{**}p < 0.01$.

Table 5. **Muscle activity (mean average voltage) during *kuzushi without tsukuri* performed with the judo ergometer (JERGo©) system and with *uke*.**

		Pulling arm			Lifting arm		
		JERGo© [µV]	***Uke* [µV]**	***p*-value (*d*)**	**JERGo© [µV]**	***Uke* [µV]**	***p*-value (*d*)**
M. deltoideus	0-30 ms	121.4 ± 92.2	275.4 ± 170.0	.001 (1.13)	72.1 ± 76.6	118.6 ± 93.2	.011 (.55)
	0-50 ms	151.4 ± 111.0	306.0 ± 173.9	.001 (1.06)	87.5 ± 82.5	149.0 ± 106.8	.014 (.64)
	0-100 ms	221.3 ± 159.2	369.3 ± 170.0	.001 (.90)	136.1 ± 98.8	237.9 ± 159.4	.012 (.77)
	0-200 ms	321.6 ± 192.8	446.6 ± 165.1	.013 (.70)	234.2 ± 151.2	368.6 ± 231.6	.013 (.69)
M. biceps brachii	0-30 ms	123.9 ± 90.6	100.4 ± 81.3	.180 (.27)	325.5 ± 283.9	234.0 ± 174.6	.109 (.39)
	0-50 ms	169.0 ± 119.3	115.3 ± 83.6	.030 (.52)	399.2 ± 324.0	287.2 ± 204.8	.071 (.41)
	0-100 ms	272.4 ± 170.4	153.9 ± 95.0	.008 (.86)	538.9 ± 379.9	442.2 ± 256.0	.147 (.30)
	0-200 ms	383.9 ± 198.8	197.6 ± 149.3	<.001 (1.06)	697.2 ± 391.3	632.5 ± 308.2	.329 (.18)
M. erector spinae	0-30 ms	319,2 ± 119.7	305.6 ± 140.3	.517 (.10)	105.9 ± 57.0	146.8 ± 79.0	.002 (.59)
	0-50 ms	322.7 ± 120.7	316.3 ± 142.1	.764 (.05)	108.9 ± 58.6	151.4 ± 79.7	.002 (.61)
	0-100 ms	329.8 ± 121.9	321.7 ± 134.4	.686 (.06)	116.7 ± 61.8	152.5 ± 77.5	.006 (.51)
	0-200 ms	345.7 ± 130.1	310.6 ± 127.1	.125 (.27)	122.0 ± 56.0	124.4 ± 61.6	.827 (.04)
M. trapezius	0-30 ms	335.9 ± 200.0	477.9 ± 276.4	.021 (.59)	244.9 ± 153.1	194.2 ± 124.8	.238 (.36)
	0-50 ms	375.8 ± 223.0	507.4 ± 297.7	.042 (.50)	297.4 ± 186.0	267.3 ± 158.4	.576 (.17)
	0-100 ms	438.4 ± 229.8	555.2 ± 301.5	.075 (.44)	370.4 ± 198.1	411.1 ± 208.7	.520 (.20)
	0-200 ms	539.3 ± 231.7	589.0 ± 250.9	.358 0.21)	449.3 ± 201.9	548.5 ± 248.5	.131 (.43)

Data was shown as mean ± standard deviation (mean ± *SD*).

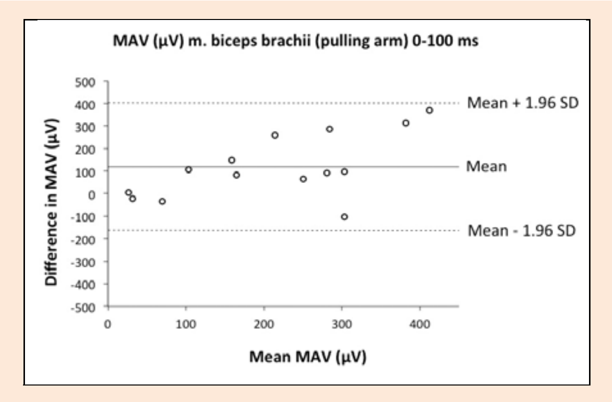

Figure 4. Bland-Altman Plot comparing the mean average voltage (MAV) of the m. biceps brachii during *kuzushi* without *tsukuri* using the JERGo© system and *uke* (n = 14). The individual differences of MAV between the judo ergometer (JERGo©) system and *uke* measurements, respectively, are plotted against the associated mean values. Solid lines indicate the average of the differences. Dotted lines indicated the limits of agreement corresponding to the mean ± 1.96 *SD*.

Discussion

We examined differences (discriminative validity) and test-retest reliability in judo-specific pulling kinetics between elite and sub-elite judo athletes during *kuzushi* movements with and without *tsukuri*. With reference to the relevant literature (Franchini et al., 2005; Kim et al., 2011; Pococco et al., 2012), we expected "excellent" correlations between repeated measurements. Additionally, better judo-specific pulling kinetics were hypothesized in both exercise conditions in elite compared to sub-elite athletes. Further, we examined ecological validity of trunk and upper limb muscle activity during *kuzushi* movements without *tsukuri* using the JERGo© system compared to the same task with *uke*. With reference to the literature (Blais et al., 2007b), we expected acceptable correlations in muscle activity between the two test conditions. The main findings of the present studies were that (i) elite athletes revealed mostly higher judo-specific pulling kinetics (mechanical work, maximal force, power) during *kuzushi* movements especially without *tsukuri* compared with sub-elite athletes; (ii) judo-specific pulling kinetics (mechanical work, maximal force) showed predominantly "excellent" test-retest reliability for both exercise conditions; (iii) the JERGo© system is able to detect "moderate" and "large" performance changes; (iv) muscle activities during the performance of *kuzushi* movements without *tsukuri* using the JERGo© system compared with *uke* indicated acceptable relative ecological validity.

Discriminative validity of judo-specific pulling kinetics

In terms of the examination of differences (discriminative validity) in judo-specific pulling kinetics between male elite and sub-elite judo athletes during *kuzushi* movements with and without *tsukuri*, our study revealed medium-to-large-sized higher judo-specific kinetics (mechanical work, maximal force, power) for elite compared to sub-elite athletes especially in *kuzushi* movements without *tsukuri*. It appears that there is a connection between high judo-specific performance (elite athletes) and JERGo©-specific performance. In other words, elite athletes outperform sub-elite athletes on the JERGo© system during *kuzushi* movements especially during the standardized *kuzushi* without *tsukuri*. Thus, the JERGo© system allows to effectively distinguish between elite and sub-elite athletes based on judo-specific pulling data.

In a previous study, Pococco et al. (2012) reported performance according to expertise levels in judo athletes. The authors observed significantly higher maximal (incremental test on an arm crank ergometer: $d = 4.30$) and mean (incremental test on a bicycle ergometer: $d = 3.62$) power outputs in senior (age: 25 ± 5 years) compared to youth (age: 15 ± 1 years) judo athletes. Further, Kim et al. (2011) reported significantly higher maximal power outputs in the 30-second Wingate test in elite athletes (Korean judo national team) with a mean age of 24 ± 3 years compared to sub-elite athletes of different age (university varsity team, mean age: 20 ± 1 years; junior varsity team, mean age: 16 ± 1 years). In addition, Franchini et al. (2005) observed significantly higher mean ($d = 0.47$) and maximal ($d = 0.52$) power outputs in the 30-second Wingate test in high performance athletes (medal winners at national and/or international competitions) compared with judo athletes who did not succeed at national and/or international competitions. Furthermore, high-performance athletes achieved a higher number of throws ($d = 1.25$) in a judo-specific fitness test compared to the less successful ones. The judo-specific fitness test consists of three time intervals (A = 15 s, B and C = 30 s) of judo activity interspersed with 10 s rest intervals. During the judo-specific fitness test, *tori* throws two *uke's*, six meters from each other using the judo technique *ippon-seoi-nage*. The reported performance differences between elite/high performance and sub-elite athletes can be explained by the fact that elite athletes compared to sub-elite athletes exhibit more training years as well as realize larger training volumes and intensities (Franchini et al., 2005; Kim et al., 2011) and/or provide a favorable genetic phenotype (Cieszczyk et al., 2010; Hermine et al., 2015; Itaka et al., 2016). These differences may induce and/or predispose to specific adaptations that allow for higher performance outputs in components of physical fitness and in sport-specific performance (Hermine et al., 2015). In terms of *kuzushi* movement with *tsukuri*, however, small-to-large-sized but non-significant higher pulling performances were observed in elite compared to sub-elite athletes. In this regard, it has to be noted that the throwing technique was standardized (i.e., *morote-seoi-nage*) throughout the study. However, *morote-seoi-nage* was not the preferred throwing technique in all of the participants. Of note, discriminative validity of a test describes the ability to assess performers of different ability (e.g., pulling force) as rated by another measure/attribute (e.g., training/expertise level) (Chaabene et al., 2018). Thus, lower discriminative validity for *kuzushi* movement with *tsukuri* may be attributed to heterogeneous proficiency levels of the participants in the throwing technique used during testing.

Test-retest reliability of judo-specific pulling kinetics

The results of test-retest reliability revealed consistent findings in mechanical work and maximal force between repeated measurements during *kuzushi* movements with and without *tsukuri*. In terms of absolute (SEM as CV, LOA) and relative (ICC) reliability, judo-specific pulling kinetics (mechanical work, maximal force) during both exercise conditions were replicable with the exception of power output. For this parameter, "poor" ICC (>0.51) and high SEM as CV values (>15%) were documented across the two testing days. This implies that the JERGo© system can be used for the assessment of training-induced changes with respect to the parameters mechanical work and maximal force. However, it appears that power output cannot be used to reliably detect training-specific adaptions of *kuzushi* movements. In addition, the JERGo© system is able to detect "moderate" and "large" performance changes in mechanical work and maximal force during *kuzushi* without and with *tsukuri*.

Ecological validity of muscle activity during a judo-specific pulling movement

In terms of the estimation of the ecological validity of muscle activity detected during *kuzushi* movements without *tsukuri* using the JERGo© system compared with *uke*, our study revealed "small-to-moderate" *r* values and non-significant differences ($p > 0.05$) in muscle activity predominantly during long time intervals (0-100 ms, 0-200 ms). In addition, LOA values revealed only a few data points outside the LOAs. Our findings in terms of ecological validity were partly in line with the literature (Blais et al., 2007b). For instance, Blais et al. (2007b), examined ecological validity of a judo-specific training apparatus during *kuzushi* movements with *tsukuri* (*morote-seoi-nage*) compared to *uke* and found significantly different pulling forces between the two exercise conditions (judo-specific training apparatus vs. *uke*). The authors explained the observed differences with discrepancies in resistance during movement execution at the training apparatus compared to the exercise with *uke* (Blais et al., 2007b). Our findings in terms of "small" to "moderate" *r* values for muscle activities can be explained by several reasons. First, the eddy current brake of the JERGo© system may not have optimally simulated resistance of *uke*, even though the system allows to individually regulate resistance of *uke* compared to *tori*.

Second, *uke* had the instruction to allow the movement at normal body tension passively and without support. It can be argued that *uke*-related resistance is particularly high at the beginning of the movement due to inertia of mass and continuously decreases thereafter with *uke's* balance instability and ultimate loss of balance. In contrast, the individually adjusted JERGo© brake load adapts less dynamically during the entire pulling movement (WP1: 100% [≤ 0 cm], WP2: 80% [≥ 20 cm], WP3: 50% [≥ 40 cm], RL: 50%) and may thus offer larger resistance. Accordingly, acceleration may differ during the *kuzushi* with *tsukuri* using the JERGo© system compared to *uke*. In fact, significantly lower acceleration values for the time interval of 0-200 ms ($p < 0.05$, $1.32 \leq d \leq 1.94$) were found for the the JERGo© system (a_x: 0.534 g, a_y: 0.460 g) compared to *uke* (a_x: 0.889 g, a_y: 0.861 g) (data not shown). Of note, acceleration of objects is the result of force production which is associated with muscular activity (Bigland-Ritchie, 1981; Laursen et al., 1998). Thus, lower *r* values for muscle activities could be explained by differences in kinetics during the *kuzushi* with *tsukuri* using the JERGo© system compared to *uke*.

Third, high LOA values in muscle activity may also be due to the JERGo© system being stationary compared to *uke*. During *kuzushi* without *tsukuri* using an opponent, *uke* changes his position during balance perturbation relative to *tori* (Imamura et al., 2006). In contrast, the eddy current brake of the JERGo© system remains in place during *kuzushi* without *tsukuri*. As a result, a direct abutment is generated during *kuzushi* without *tsukuri* using *uke* compared to the JERGo© system, which has a direct influence on the resulting force vectors (Fig. 1a-b). This explanation is supported by the study of Rahemi et al. (2014) who showed that force direction and/or magnitude were significantly affected by the activation pattern of the respective muscles.

With respect to the LOA values, long time intervals (0-100 ms, 0-200 ms) indicated a larger dispersion compared to short time intervals (0-30 ms, 0-50 ms). The systematic error between muscle activity levels during *kuzushi* movements using the JERGo© system compared to *uke* was also large, especially for the lifting arm during the long time intervals. The observed poor reliability in long compared to short time intervals might be explained by the fact that the probability of recording variations in the movement execution increases with the length of the analyzed time interval.

Limitations

First, we have to acknowledge the significant chronological age difference between elite and sub-elite athletes (study 1). In this regard, although two performance level groups in a similar sport setting were recruited, the established discriminative validity may not explicitly be attributed to the advanced training experience of the elite athletes. According to Chaabene et al. (2018), difference in one measure/attribute (e.g., training level) is a precondition to determine discriminative validity of a test and the respective outcome measures. However, the present findings may partly be a result of other non-controlled factors (e.g., age) as well. Future studies should compare groups of similar chronological age but different training expertise (e.g., elite vs. sub-elite) to substantiate the present findings on discriminative validity of the new judo ergometer system. Second, it is noteworthy that the mechanical limit of the JERGo© system does not exceed the maximal resistance of 1,000 N. Thus, the same mechanical resistance was used for the assessments of athletes belonging to the weight categories -100 kg and +100 kg. This may likely underload +100 kg athletes during testing.

Conclusion

Findings from this study revealed that the judo-specific ergometer allows detecting performance differences in judo-specific *kuzushi* kinetics (mechanical work, maximal force, power) especially during *kuzushi* without *tsukuri* between elite and sub-elite athletes. In addition, the results showed reliable measures for the JERGo© system, particularly for the parameters mechanical work and maximal force. Furthermore, we observed acceptable correlations, particularly for short time intervals at the beginning of the *kuzushi* movement for muscle activities during *kuzushi* without *tsu-*

kuri using the JERGo© system compared with *uke*. Even though muscle activities during *kuzushi* without *tsukuri* using the JERGo© system were not identical compared to those with *uke*, similar neuromuscular activation patterns were observed for both exercise conditions. From a practitioner's point of view and with reference to our data, the JERGo© system can be used for testing and training of judo-specific pulling kinetics (mechanical work, maximal force) during *kuzushi* movements. For the JERGo© system, this is achieved through the individual application of resistance loads according to the athletes' weight category. Thus, comparable loads can be simulated when working with the JERGo© system compared to *uke*. Finally, the JERGo© system allows the direct presentation of judo-specific performance data during the *kuzushi* movement (kinetic parameters, displacement characteristics). Both, the standardized movement and immediate feedback during training (knowledge of performance and results) clearly propagate the application of the JERGo© system during training to facilitate learning processes. Taken together, findings from this study indicate that the JERGo© system can be implemented in the training process to optimize *kuzushi* movements particularly without *tsukuri*.

Acknowledgements

The preparation of the two studies (AZ 071611/12-13 and AZ 071610/13-14) was supported by the German Federal Institute of Sport Science (Bonn, Germany). The authors would like to specifically thank Y. Bönisch, M. Schendel, A. Kirchner, Prof. Dr. D. Büsch, Dr. H.-D. Heinisch, and L. Heine for their support in the recruitment of athletes. In addition, the authors would like to thank the Institut für Forschung und Entwicklung von Sportgeräten (FES) Berlin, Germany for assistance with the application of the JERGo© system. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

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Key points

- The judo-specific ergometer system (JERGo©) is able to detect judo-specific pulling kinetics and force displacement characteristics for the lifting and pulling arm during judo-specific movements.
- The individual adjustment of the JERGo© system (i.e., height of lifting arm, pulling arm, brake resistance) is interlocked by athletes' weight category and body height as well as the preferred judo technique.
- The JERGo© system is a valid and reliable test instrument for assessment and training of judo-specific pulling kinetics.

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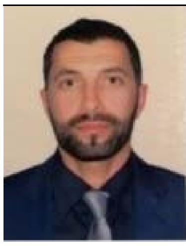

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