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Heart rate and blood lactate response along with grip strength deterioration during successive judo simulations (randori)

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Abstract

Introduction. **Judo requires highly technical and tactical skills with physiological response optimization to succeed.** Aim of Study. **The present study aims to investigate an association between a rating of perceived exertion (RPE), a heart rate (HR), and a blood lactate concentration [La⁻] along with a grip strength (GS) deterioration in successive judo simulations (randori).** Material and Methods. **Ten male judokas performed six successive fights (randori), of 5-minute each, with 5-minute rests. The HR, [La⁻], GS, and grip activation time (GAT) were recorded with a standard procedure at various time points (resting – T0 and after each bout T1-T6).** Results. **The HR and [La⁻] showed significant ($p < 0.001$) differences when compared among T1-T6, including T0, but a variation in the HR (ΔHR) and a variation in the lactate concentration (Δ[La⁻]) reported no significant difference after a post-simulation data comparison. The GS (for both dominant and non-dominant hand) reported significant differences among post-simulation GS measurements, including T0. The GAT was negatively and significantly ($p < 0.01$) correlated with GS-right ($r = –0.397$) and GS-left ($r = –0.440$). Similarly, the RPE was positively correlated with the ΔHR, Δ[La⁻], HR, and [La⁻]. Whereas the GS (for both hands) was negatively ($p < 0.05$) correlated with the Δ[La⁻] and [La⁻]. Finally, the ΔHR was positively ($p < 0.01$) correlated with the Δ[La⁻] and [La⁻].** Conclusions. **Judo simulations involve high-intensity exercises, leading to a maximum average frequency RPE of 7-9 with an HR of 192-193 beats·min^{-1} (90-95% HR_{max}) and 9.79-15.41 mmol·L^{-1} of peak [La⁻]. The RPE was positively (significantly) correlated with the ΔHR, Δ[La⁻], HR, and [La⁻]. Whereas the GAT was negatively (significantly) correlated with the GS-right and GS-left.**

KEYWORDS: lactate response, progressive judo simulations, heart rate response, grip strength activation, muscular strength deterioration.

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Introduction

Competitive judo requires high-intensity intermittent actions that demand technical, tactical, and skillful development along with optimized physiological response to succeed [11, 22]. Judo training is a combination of a restricted diet and aerobic exercises, with a typical goal of quick fat mass reduction [22]. Successive judo bouts cause fatigue and considerable deterioration in physical capabilities, which result in performance deterioration during matches [2, 19]. Therefore, a judo competition with successive judo matches involves physiological, strength-related [15], metabolic, and technical or tactical variables, and therefore causes a higher fatigue rate [8, 11].

Previously, Branco et al. [5], Laskowski et al. [14], and Torres-Luque et al. [22] have depicted importance of a heart rate and lactate response during competitive bouts which gives an idea about intensity and perceived exertion during judo matches. As competitive judo bouts progress, athletes significantly lose muscular strength, and a decrease in force production is also correlated with progressive physical exhaustion [4]. After three fight simulations, Serrano et al. [18] and Branco et al. [5]

have reported a strong correlation between a rating of perceived exertion (RPE) and a blood lactate concentration [La⁻] peak ($r = 0.64$, $p < 0.05$) in the first fight, $r = 0.71$, $p < 0.05$ after the first bout, and $r = 0.92$, $p < 0.05$ after the second bout. Whereas, Bonitch et al. [1] and Branco et al. [5] have noted a strong correlation between a heart rate (HR) and a measured RPE after competition with $r = 0.86$ to 0.88 ($p < 0.01$) and $r = 0.70$ to 0.64 ($p < 0.05$), respectively.
Previously, Branco et al. [5], Laskowski et al. [14], and Torres-Luque et al. [22] have presented physiological characteristics of judo players. Whereas, Serrano-Huete et al. [19] and Bonitch-Domínguez et al. [2] have reported exertion in muscular strength, especially handgrip strength. However, there is still a gap regarding a rate of force depletion during repeated simulated bouts and how a particular muscular strength activation time is exactly correlated with a decrease of force exhaustion. The present study aimed to investigate a heart rate and lactate response along with grip strength exertion during repeated simulated judo matches (randori). The study further clarified a relationship between grip activation time (GAT) and physiological response variables, force depletion, and winning scores.

Material and Methods

Ten male judo players ($n = 10$, mean age = 21.33 ± 3.96 years) were recruited as subjects for the present study. Particulars of the selected judokas were as follows: body height = 176.20 ± 7.34 cm, body weight = 79.47 ± 10.41 kg, body mass index (BMI) = 25.55 ± 2.43 kg/m^2. All participants had minimum 4 years of professional training experience and were only recruited after a clinical examination. Written informed consent was obtained from each player and the study protocol conformed to the ethical guidelines of the Declaration of Helsinki. Ethical clearance was obtained from the Institutional Ethical Committee (IEC).

Training regimen

The study was conducted during a preparatory phase, when athletes train judo at least 90 minutes per day for 5 days/week. During this time, typical judo training sessions included a 15-minute warm-up that simulated lone attacks (shadow uchikomi), calisthenics drills, and fall simulations for self-defense. Following this, the main part of the training session consisted of a 30-minute standing judo fight simulation (randori), a 15-minute intermittent groundwork fight simulation (ne-waza), 20-minute intermittent set forms in pre-established sequences of defensive and offensive movements, a 10-minute cool-down, and a 20-minute intermittent technique entrance practice (uchikomi) [5, 6].

Fight simulations

Athletes of the same weight category were randomly divided into pairs in order to perform six fight simulations (randori), of 5 minute each (regardless of an ippon occurrence), separated by 5-minute passive recovery periods. After each randori, the pairs were modified in order to maintain variety of actions equivalent to those encountered in competition. The simulations took place between 10 am and 12 pm at an average temperature of 28 °C [5]. All participants experienced the same temperature, humidity, lighting, and dojo conditions during the fight simulations. The study's protocols had been previously explained to the athletes.

Anthropometric variables

General physical characteristics, i.e., body height (cm) and body weight (kg), were measured using a Seca Alpha stadiometer (model – 213, Seca Deutschland, Germany) with 0.1 cm precision and a Seca Alpha weighing scale (model – 770, Seca Deutschland, Germany) with 0.1 kg precision, respectively. BMI was calculated using a standard formula [16].

Muscular strength indices

A digital handgrip dynamometer (TKK 5101 Grip D; Takey, Tokyo, Japan) was used to record the grip strength (GS) in kg, according to considerations of previous studies [10, 19]. The optimal grip was adjusted according to a calibration formula. The participants were encouraged to achieve maximum isometric handgrip strength in four different directions, i.e., vertically down 0°, horizontally side 90°, horizontally forward 90°, and vertically up 180° for both hands. At all times, the GS of both hands was recorded as dominant hand strength (DHS) and non-dominant hand strength (NDHS). Resting GS was recorded as T0 (time 0 as resting), then marked as T1, T2, T3, T4, T5, T6 after each fight. Variations (Δ) in the GS were expressed as ΔGS and a decline in a strength profile after each simulation was calculated and recorded.
Maximum absolute strength (AS) is a maximum value of strength obtained in a maximum handgrip test and maximum relative strength (RS) is considered absolute strength divided by a body mass of a subject. Peak strength fatigue index (PSFI) indicates a percentage of decrease in force over 10 sets during an isometric handgrip test, using peak values of the sets in the following equation: {[a repetition with the highest peak

force during the test – a repetition with the lowest peak force during the test] × 100 ÷ a repetition with the highest peak force during the test}. Mean strength fatigue index (MSFI) indicates a percentage of decrease in force over 10 sets during an isometric handgrip strength test, using mean values of the sets in the following equation: {[a repetition with the highest mean force during the test – a repetition with the lowest mean force during the test] × 100 ÷ a repetition with the highest mean force during the test} [12].

During the 5-minute judo simulations, the grip force was not activated for the entire duration of the bouts. Therefore, the GAT was counted as the time during which the hand grip strength was actually producing force or contraction. The GAT was recorded visually and using a handheld stopwatch (CASIO HS-70W-1DF Stopwatch, Casio India Co. Pvt Ltd) [12].

Physiological profile

The six repeated judo bout (randori) simulations were performed and after each bout the muscular strength (grip strength) and physiological variables (HR, [La$^-$]) were measured for each subject. Resting measures of the GS and assessments of the physiological indices were also recorded under pre-exercise conditions. Pre-exercise objective measures for the HR and [La$^-$] were recorded as T0, then after each bout they were marked as T1, T2, T3, T4, T5, and T6. Variations (Δ) in the HR, [La$^-$], and the CR-10 RPE were expressed as a ΔHR, Δ[La$^-$], and ΔRPE, respectively.

The HR was monitored using HR sensors (Polar Model F11, Kempele, Finland) and expressed in beats per minute (bpm). A blood lactate [La$^-$] analysis was performed using a portable lactate analyzer (Lactate Scout 4, EKF Diagnostics) and expressed in mmol·L^{-1} [5].

Along with the HR and [La$^-$], another objective measure of the RPE (the Brog CR-10 scale) was recorded, in which the participants were asked to indicate any number on a scale from 0 to 10 to classify their global effort. Latency or no exertion was associated with a 0 rating, while 10 was considered maximum effort. All participants were familiarized with the rating scale before the measurement [4].

Statistical analysis

Data was analyzed using the Statistical Package for the Social Sciences (SPSS) software for Windows, version 19.0 (SPSS, Inc., Chicago, IL, USA) was used to analyze the data, with a significance level of $p \leq 0.05$. The data was presented as means and SDs. Statistical tests, such as the Levene's test and the Shapiro–Wilk test, confirmed that the data was normally distributed. The one-way repeated measures analysis of variance (ANOVA) was used to compare the data between a pre- and post-test. For post hoc evaluations of pairwise differences, the Bonferroni's test was applied. Additionally, the Pearson correlation analysis was also performed. Differences in all variables from pre- to post-fight results were calculated as variable variance (Δ).

Results

Table 1 depicts a comparative analysis of the HR and [La$^-$] responses among the successive judo simulations. Significant ($p < 0.001$) differences were reported in the HR and [La$^-$] when compared among the simulations (T1-T6), including the resting data. The Bonferroni's post hoc analysis clearly depicts that the resting HR and [La$^-$] significantly differed from the post-simulation values. However, the ΔHR and Δ[La$^-$] data was not significantly different when compared among all post-simulation data.

Table 2 depicts a comparative analysis of the handgrip strength (both dominant and non-dominant hand) during the repeated judo simulations. A comparison of initial/resting GS values and all post-simulation GS measurements shows significant differences between hands. However, those differences were presented at various levels of statistical significance. On the other hand, when the ANOVA was used to perform the comparison among GS values of various post-simulations, it showed no statistically significant differences. Nevertheless, a consistent decrease (both in peak and average strength measures) in the GS with a progression of the simulations was clearly observed from the data set.

Table 3 depicts a comparative analysis of the RPE and GAT, which shows no statistical difference in the post-simulation data (T1-T6) for both the RPE and GAT. This result presents that the RPE is mainly in the range of 6-10, while the GAT is in the range of 83.00-208.00 throughout the six progressive judo simulations.

Table 4 depicts the Pearson correlation matrix of the GS, HR, [La$^-$], RPE and GAT. The GAT was shown to be negatively and significantly ($p < 0.01$) correlated with GS-right ($r = -0.397$) and GS-left ($r = -0.440$). Similarly, the RPE was positively and significantly correlated with the ΔHR, Δ[La$^-$], HR, and [La$^-$]. Whereas, both the right and left hand GS were negatively and significantly ($p < 0.05$) correlated with the Δ[La$^-$] and [La$^-$]. Finally, the ΔHR was positively and significantly ($p < 0.01$) correlated with the Δ[La$^-$] and [La$^-$].

Table 1. Comparative analysis of heart rate and blood lactate concentration parameters among various judo fight simulations

Simulations	HR (beats·min^{-1})	[La$^-$] (mmol·L^{-1})	ΔHR	Δ[La$^-$]
T0	72.20 ± 6.55	1.77 ± 0.43	resting	
T1	192.80 ± 14.99	10.32 ± 2.65	120.60 ± 17.65	8.55 ± 2.50
T2	190.30 ± 12.80	12.60 ± 2.81	118.10 ± 16.64	10.83 ± 2.60
T3	192.30 ± 17.81	11.51 ± 2.70	120.10 ± 21.56	9.74 ± 2.59
T4	189.50 ± 14.26	10.24 ± 2.44	117.30 ± 14.18	8.47 ± 2.23
T5	192.60 ± 10.36	11.36 ± 2.52	120.40 ± 10.76	9.59 ± 2.47
T6	193.10 ± 14.00	11.45 ± 1.76	120.90 ± 19.98	9.68 ± 1.75
F value	113.955	24.921	0.075	1.349
Sig.	<0.001***	<0.001***	0.996^{NS}	0.258^{NS}
Post hoc	T0 vs T1, T2, T3, T4, T5, T6	T0 vs T1, T2, T3, T4, T5, T6		

Note: NS – not significant, HR – heart rate, [La$^-$] – blood lactate concentration, ΔHR – difference change in heart rate, Δ[La$^-$] – difference change in blood lactate, T0 – resting value, T1 – 1st bout simulation, T2 – 2nd bout simulation, T3 – 3rd bout simulation, T4 – 4th bout simulation, T5 – 5th bout simulation, T6 – 6th bout simulation, Sig. – level of significance
Values are mean ± SD.
*** p < 0.001

Table 2. Comparative analysis of handgrip strength variables of dominant and non-dominant hand among various judo fight simulations

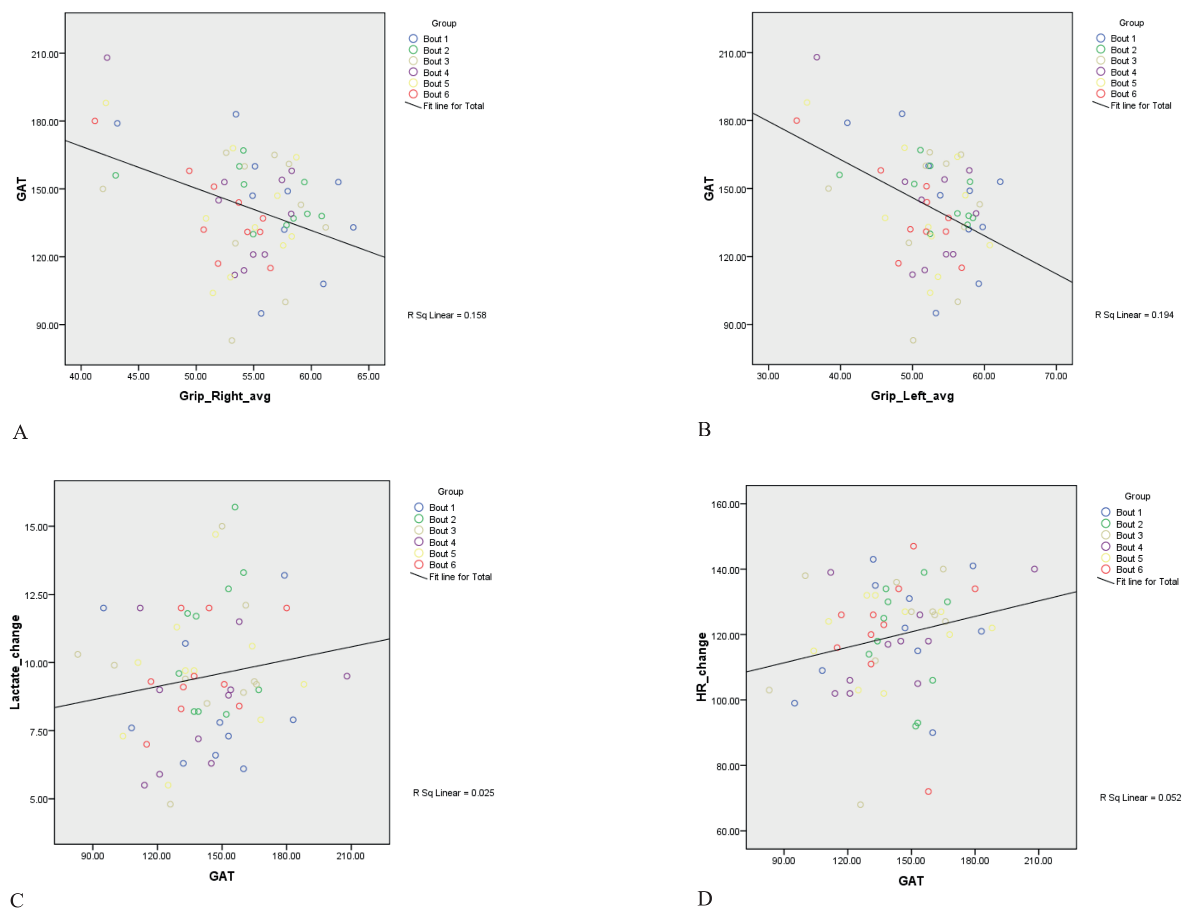
Simulation bouts	DHS (kg)		NDHS (kg)	
	Peak	Average	Peak	Average
T0	60.12 ± 5.70	59.25 ± 6.30	57.25 ± 7.37	56.60 ± 7.58
T1	57.35 ± 6.02	56.49 ± 5.80	55.48 ± 6.48	54.58 ± 6.30
t-value (p)	4.235 (0.002)**	5.192 (0.001)**	3.455 (0.007)**	3.799 (0.004)**
T2	56.41 ± 4.65	55.62 ± 5.15	54.50 ± 5.60	53.42 ± 5.70
t-value (p)	6.009 (<0.001)***	5.258 (0.001)**	3.267 (0.010)*	4.748 (0.001)**
T3	56.79 ± 5.27	54.82 ± 5.37	53.59 ± 6.49	52.65 ± 5.98
t-value (p)	3.446 (0.007)**	5.970 (<0.001)***	3.924 (0.003)**	4.657 (0.001)**
T4	55.11 ± 4.77	53.91 ± 4.69	52.81 ± 6.75	52.01 ± 6.29
t-value (p)	5.922 (<0.001)***	6.682 (<0.001)***	4.637 (0.001)**	5.349 (<0.001)***
T5	55.19 ± 5.16	53.73 ± 4.96	52.69 ± 7.28	51.57 ± 7.03
t-value (p)	5.942 (<0.001)***	6.797 (<0.001)***	3.008 (0.015)*	5.244 (0.001)**
T6	53.13 ± 4.45	52.36 ± 4.65	50.98 ± 6.90	49.96 ± 6.56
t-value (p)	6.987 (<0.001)***	8.199 (<0.001)***	4.431 (0.002)**	6.694 (<0.001)***
F value	1.782	1.908	0.934	1.098
Sig.	0.117^{NS}	NS	0.477^{NS}	NS

Note: DHS – dominant handgrip strength, NDHS – non-dominant handgrip strength, T0 – resting value, T1 – 1st bout simulation, T2 – 2nd bout simulation, T3 – 3rd bout simulation, T4 – 4th bout simulation, T5 – 5th bout simulation, T6 – 6th bout simulation, Sig. – level of significance, p – p-value, NS – not significant
Values are mean ± SD.
* p < 0.05; ** p < 0.01; *** p < 0.001

Table 3. Comparative analysis of rating of perceived exertion and grip activation time variables among various judo fight simulations along with the simulations-wise range of distribution

Simulations	RPE	GAT (sec.)	RPE range	GAT range
T1	7.50 ± 0.71	143.90 ± 28.04	6.00-8.00	95.00-183.00
T2	7.90 ± 0.99	146.60 ± 12.52	6.00-9.00	130.00-167.00
T3	7.60 ± 1.17	138.70 ± 28.53	6.00-10.00	83.00-166.00
T4	7.50 ± 1.43	142.50 ± 28.78	5.00-10.00	112.00-208.00
T5	7.50 ± 1.35	140.60 ± 26.35	6.00-10.00	104.00-188.00
T6	7.60 ± 1.17	139.60 ± 19.57	6.00-10.00	115.00-180.00
F value	0.177	0.143	overall range (T1-T6)	
Sig.	0.970NS	0.981NS	5.00-10.00	83.00-208.00

Note: RPE – rating of perceived exertion, GAT – grip activation time, T0 – resting value, T1 – 1st bout simulation, T2 – 2nd bout simulation, T3 – 3rd bout simulation, T4 – 4th bout simulation, T5 – 5th bout simulation, T6 – 6th bout simulation, Sig. – level of significance, NS – not significant
Values are mean ± SD.



Grip (Right) – grip strength (right hand), Grip (Left) – grip strength (left hand), GAT – grip activation time, ΔHR – difference change in heart rate, Δ[La] – difference change in blood lactate concentration
Figure 1. Scatter-plot between (A) Grip (Right) vs GAT, (B) Grip (Left) vs GAT, (C) GAT vs Δ[La], (D) GAT vs ΔHR

Table 4. Pearson correlation coefficient among grip strength, heart rate, lactate, rating of perceived exertion, and grip activation time

Variables	RPE	Grip (R)	Grip (L)	ΔHR	Δ[La⁻]	HR	[La⁻]
GAT	0.034	–0.397**	–0.440**	0.228	0.159	0.228	0.159
RPE		–0.029	–0.060	0.322*	0.367**	0.322*	0.367**
Grip (R)			0.953**	–0.088	–0.261*	–0.088	–0.261*
Grip (L)				–0.059	–0.295*	–0.059	–0.295*
ΔHR					0.341**	1.000**	0.341**
Δ[La⁻]						0.341**	1.000**

Note: GAT – grip activation time, RPE – rating of perceived exertion, Grip (R) – handgrip strength (right hand), Grip (L) – handgrip strength (left hand), ΔHR – difference change in heart rate, Δ[La⁻] – difference change in blood lactate concentrations, HR – absolute heart rate value, [La⁻] – absolute blood lactate concentrations
r = correlation coefficient
* $p < 0.05$; ** $p < 0.01$

Figures 1(A) and 1(B) depict a relation between the GS-right vs GAT (R^2linear = 0.158) and the GS-left vs GAT (R^2linear = 0.194), respectively. Similarly, Figures 1(C) and 1(D) show a relation between the GAT vs Δ[La⁻] (R^2linear = 0.025) and the GAT vs ΔHR (R^2linear = 0.052), respectively.
Table 5 depicts an analysis of the PSFI and the MSFI counted during the successive judo simulations of maximal isometric handgrip strength testing. The PSFI of both directions, 90° side and 90° forward, along with the MSFI were found to show no significant difference when compared between DHS and NDHS.

Table 5. Comparative analysis of peak strength fatigue index and mean strength fatigue index of maximal isometric handgrip strength testing during successive judo simulations

Variables		Mean ± SD	t-value	Sig.
90° side	PSFI (%) DHS	12.65 ± 2.89	–0.448	0.381^{NS}
	PSFI (%) NDHS	13.17 ± 2.21		
90° forward	PSFI (%) DHS	13.58 ± 3.89	0.396	0.243^{NS}
	PSFI (%) NDHS	12.98 ± 2.90		
Average	MSFI (%) DHS	12.71 ± 2.49	–0.153	0.190^{NS}
	MSFI (%) NDHS	12.86 ± 2.05		

Note: DHS – dominant handgrip strength, NDHS – non-dominant handgrip strength, PSFI – peak strength fatigue index, MSFI – mean strength fatigue index, Sig. – level of significance, NS – not significant
Values are mean ± SD.

Discussion

The main aim of the present study was to determine the heart rate and lactate response along with the grip strength deterioration during the successive judo simulations (randori). Judo is considered a high-intensity exercise sport [13], involving continuous muscular force production [19]. According to the results obtained, the physiological markers indicated that judokas need more time in between two simulations to return to a baseline. The HR has been used not only to quantify training intensity, but the HR response also contributes to monitoring of aerobic capacity and recovery conditioning [1, 22]. In the present study the HR_{rest} was reported to be around 72 beats·min^{-1}, increasing to 192 beats·min^{-1} after the 1st bout and reaching 193 beats·min^{-1} after the 6th bout simulation. The present study also clarified that the HR increased after each simulation bout and consistently reached 192-193 beats·min^{-1} after the 5th-6th bout, which corresponds to >95% of an age-predicted HR_{max} value. The present study results are in agreement with previous study reports by Degoutte et al. [7], Bonitch et al. [1], and Torres-Luque et al. [22]. In the review by Torres-Luque et al. [22], the researchers have found that male judokas' HR_{rest} values were between 54 and 65 beats·min^{-1}, and that during competitions their mean HR was 180 to 182 beats·min^{-1}, or 85% to 90% of their HR_{max}. The HR_{max} of men during judo contests ranged from 190 to 200 bpm and was slightly lower for women [1, 7, 22]. Similarly, Serrano-Huete et al. [19] have reported that an HR increased during successive judo bouts from 177.17 beats·min^{-1} in a 1st bout to 185.69 beats·min^{-1} in a 5th bout.
On the other hand, the present study revealed that the ΔHR (HR change) among the successive judo simulations against the resting value was reported to be around 117-120 beats·min^{-1}, which indirectly corresponds to the absolute HR around >95% of the age-predicted HR_{max}

value [20]. The HR response during the successive judo simulations may indicate that judo requires a high level of cardiorespiratory fitness to sustain the intermittent judo matches, and a similar level even for the training phases [17]. According to Torres-Luque et al. [22], the most common efforts during judo training were in order to form the highest to the lowest intensity, as in randori and uchikomi, and during these intermittent training bouts, the HR reached around 183 beats·min^{-1} from 95 beats·min^{-1} in resting. Interestingly, the present study revealed that the increase in the HR was positively and significantly correlated with the increase in the [La$^-$] and grip activation duration, and similar findings were also reported by Stavrinou et al. [21].

The present study has depicted that the resting [La$^-$] was 1.77 mmol·L^{-1}, which increased to 10.32 mmol·L^{-1} after the 1st bout and reached 11.45 mmol·L^{-1} after the 6th bout. The present study clarifies that with each progressive bout, the [La$^-$] increased, which may indicate physical exhaustion and physiological fatigue, with the official minimum recovery time (the gap between the bouts) being insufficient for the [La$^-$] to return to the baseline and provide complete recovery. The [La$^-$] values after the bout simulations were >10 mmol·L^{-1}, indicating a moderate to high demand for the glycolytic system. The present study results are in agreement with previous study reports by Degoutte et al. [7], Laskowski et al. [14], and Sbriccoli et al. [17]. While Degoutte et al. [7] and Sbriccoli et al. [17] have reported that a [La$^-$] after a judo fight reached around 12.3 mmol·L^{-1} and 9.9 mmol·L^{-1} respectively, the highest registered value of around 25.1 mmol·L^{-1} was reported by Laskowski et al. [14]. Interestingly, the highest observed [La$^-$] was about two times higher than lactate reported by Degoutte et al. [7] and Sbriccoli et al. [17]. On the other hand, Laskowski et al. [14] have reported in their study that a [La$^-$] tends to rise with match simulations progression, from 11 mmol·L^{-1} after a 1st round to 25.1 mmol·L^{-1} after a 4th round, whereas 2nd, 3rd and 4th bouts consistently resulted in a very high [La$^-$] around 21.3-25.1 mmol·L^{-1}. The increase in [La$^-$] may be a sign of high-intensity activity that triggers the glycolytic process and increases lactate tolerance, which helps athletes concentrate on hydrogen ions and perform at their best [20]. However, values during real competitions has been reported to be approximately 2-3 mmol·L^{-1} lower than during repeated training simulations, which suggests that bout simulations impose a lower glycolytic demand than a real competition [9]. These findings also indicated that the judo players' [La^{-}] increased in response to isometric muscle tension, which results in muscle hypoxia, accelerates glycolysis and induces muscle hypoxia [14, 23].

The Borg scale [19] can be used to monitor metabolic and cardiovascular stress during official judo matches, and has reported significant data that is consistent with physical fatigue conditioning. In the present study the judokas were reported to have the 6-10 scale rating in the RPE (under the 10-scale rating system) after the repeated successive judo simulations, which again identified a stress load of judo bouts as moderate to high. However, Bonitch et al. [1] have found that [La$^-$] levels were significantly correlated with a RPE and concluded that the RPE can be used to monitor cardiovascular stress during judo bouts. Interestingly, in the present study, the RPE had almost no significant correlation with the GS of both hands (GS-right, R^2linear = 0.004; and GS-left, R^2linear = 0.0008), whereas the correlation study showed that the GAT had almost no correlation of dependency on the RPE (R^2linear = 0.001, Pearson correlation coefficient = 0.034).

The present study reported the progressive deterioration of the GS in both dominant (DHS) and non-dominant (NDHS) hand, parallelly with the progression of the successive judo simulations. The comparison of T0 and T6 showed 11.6% for the GS deterioration and 10.9% for the peak strength (DHS and NDHS), and 11.6% and 11.7% for the average strength (DHS and NDHS), respectively. The present result is in agreement with studies by Serrano-Huete et al. [19] and Bonitch-Góngora et al. [3], in which a decline in GS was shown to take place maximally >10%, and a deterioration rate increased with a progression of matches. In contrast, Bonitch-Góngora et al. [3] have showed that GS of both hands declined in the course of subsequent matches, with the GS of dominant hand deceasing by 15% after four matches and by 12.7% after one match. Similarly, Serrano-Huete et al. [19] have reported a 5% reduction in GS after a first match and a 15% reduction after a second bout. Torres-Luque et al. [22] have showed that a range of GS of male judokas varied from 46.5-64.3 kg and 42.0-69.0 kg of a right and left hand, respectively. In the present study, the peak GS varied from 53.13 ± 4.45 kg to 60.12 ± 5.70 kg for DHS (the peak value) and 50.98 ± 6.90-57.25 ± 7.37 kg for NDHS (the peak value). Similarly, the present study reported that the average GS varied from 52.36 ± 4.65 kg to 59.25 ± 6.30 kg for DHS (the average value) and 49.96 ± 6.56-56.60 ± 7.58 kg for NDHS (the average value). Although all deteriorations of the GS after each simulation bout (T1 to T6) were found to be significantly decreased/reduced in comparison to the resting (T0) value, which might reveal the game demand of judo, the nature of the game requires from judokas the high level of GS and grip activation during a fight, which ultimately uses the muscular endurance power repeatedly, eventually causing fatigue in the grip muscles [19, 22].

The present study also focused on the GAT, which is duration of GS used to grip an opponent during the total bout time of simulations (T1 to T6 total bout time). The present result shows that the higher GAT (146.60 ± 12.52 sec.) has the higher RPE (7.90 ± 0.99) after the T2 bout, along with the higher decline in GS in the course of the successive judo simulations. Serrano-Huete et al. [19] have also reported a high correlation between higher values of GS in a dominant hand and a high RPE of a bout. Both the right and left GS have a negative significant correlation with the GAT with R^2linear = 0.158 (Pearson correlation = –0.397, $p < 0.01$) and R^2linear = 0.194 (Pearson correlation = –0.440, $p < 0.01$). On the other hand, the GAT has a positive correlation with the ΔHR (R^2linear = 0.052) and Δ[La^-] (R^2linear = 0.025), although the changes were not significant in the correlation matrix study.

The highest PSFI (%) and the MSFI (%) were reported in the present study after the successive judo simulations (T1-T6 summarized). The PSFI (90° side and 90° forward) was reported to be around 12.65-13.58% for both the dominant (DHS) and non-dominant hand (NDHS), and the MSFI value was 12.71% (DHS) and 12.86% (NDHS). Thus, the present study revealed that after the six (T1-T6) progressive judo simulations, the muscular fatigue related to the grip strength was generated >12% (both hands) and there was no difference in dominance of strength in the dominant or non-dominant hand. The handgrip strength activation during the judo simulations might lead to a potentiation of muscular strength and endurance, resulting in greater red muscle fiber activation, and the high-intensity phases potentiate both energy systems (endurance and anaerobic) to work optimally at that position, which maximally accumulates the [La^-], leading to physical fatigue [12]. Interestingly, the present study depicted that the higher GAT will correlate with the higher PSFI and MSFI values, along with the higher HR and [La^-] alterations.

One of the major strengths of this study was that it mimicked the exact conditions as during a judo competition, with the same official operating protocol. Therefore, the present study reported the same or similar effort as in an official judo competition and depicted similar physiological responses. In addition, the effects of the judo simulations or the exact bouts on the physiological responses were clarified, such as the impact on the muscular strength measures and force production. Some of the data considers visual processing (GAT), which might have some human interface limitations.

The present study has some limitations. Firstly, the number of subjects was very small, which is a limitation of the study. There are resource limitations and lack of female athletes, so only male athletes were considered in the study. Due to the resource limitations, the authors also failed to record the exact fight points during the successive judo matches, which might help to correlate the physiological response with the real-time match scoring.

Conclusions

The current study depicted that the judo simulations amount to a high-intensity intermittent exercise session that produces a high level of variable indications, i.e., the physiological variables ([La^-], HR) changes. In this regard, the capacity of muscular (handgrip) strength production was significantly reduced with the progression of the successive judo bouts, and the muscular strength deterioration was reported to be positively correlated with the rising levels of HR and [La^-] response during the successive judo simulations. The post-simulation HR was reported to be around >95%, regardless of the number of simulations. However, the bouts T5 and T6 correspond to the highest measurement of 192-193 beats·min^{-1}, whereas the [La^-] was measured to be the highest at 9.79-15.41 mmol·L^{-1} after the T2 simulations. The GS was shown to deteriorate significantly as the simulations progressed from T1 to T6: the highest values for T0 were 60.12 kg (DHS) and 57.25 kg (NDHS), while for T6 the values were 53.13 kg (DHS) and 50.98 kg (NDHS). On the other hand, the PFSI and MFSI of both dominant and non-dominant hand have reported the 12-13% strength fatigue index after the six successive simulations. The GAT also depicted the positive correlation with the RPE of the judo simulations and muscle strength deterioration. An intermittent judo simulation requires a great amount of energy and muscular strength along with cardiorespiratory fitness to maintain optimal performance. Physical and physiological exhaustion may limit judokas' ability to perform optimally, which may be reflected by muscular strength deterioration, increasing levels of a HR and [La^-] response during successive judo simulations.

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Conflict of Interest

The authors declare no conflict of interest.

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