

# Gender differences in elite athletes heart rate dynamics following a supra maximal complex effort

## Abstract

Regarding the importance of recovery in sport performance, assessment of post-exercise Heart Rate (HR) Dynamics has become a useful tool to understand such an individual process. Heart Rate Variability (HRV) analysis is widely used as a non-invasive marker of Autonomic Nervous System regulation of HR, where the nonlinear methods (Detrended Fluctuation Analysis (DFA)) have become a promising complementary analysis technique. In order to deepen on the effects of supra maximal complex efforts, integrating specific endurance and strength requirements on cardiac autonomic regulation, our research group is working in different protocols looking for the analysis of specific responses under supra maximal exertion. Therefore, our purpose was to analyze the immediate 10 min recovery timeline following a supra maximal specific Judo test in twenty-four judokas from the Spanish National Team (16 males and 8 females, 24.40±0.97 years), deepening on gender differences. Consistent with previous research on supra maximal protocols, both HRV indices and Short-Term Scaling Exponent ( $\alpha_1$ ), stemmed from DFA, appeared severely depressed after the test. Moreover, a negative correlation was found between final isometric pull-up drill and both lnTP ( $r=-0.457$ ;  $p<0.05$ ) and lnLF ( $r=-0.496$ ;  $p<0.05$ ), thus suggesting a crucial role for isometric strength requirements in cardiac autonomic recovery after exercise. At the same time, while performance showed a large gender difference ( $p<0.05$ ;  $d=0.90$ ), no significant gender differences were found either in HRV indices or in  $\alpha_1$ . However, when analyzing distance scores to optimal value of  $\alpha_1=1$  ( $|1-\alpha_1|$ ), men displayed significantly greater results, thus implying an improved recovery ability. Eventually, our results corroborate that nonlinear methods, compared to linear HRV indices, are capable of detecting subtler changes in HR behaviour.

**Keywords:** Detrended fluctuation analysis, fatigue, heart rate variability, judo, recovery, specific endurance, stamina

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**Abbreviations:** HRV, heart rate variability; ANS, autonomic nervous system; HR, heart rate; DFA, detrended fluctuation analysis; BSJT, blasco specific judo test; VO<sub>2</sub>max, maximum oxygen consumption; SDNN, standard deviation of normal R-R intervals; Rmssd, root mean square difference of successive normal R-R intervals; LF, low frequency power; HF, high frequency power; TP, total power; SPSS, statistical package for the social sciences; ES, effect size; SD, standard deviation; RFD, rate of force development; TL, PU, time limit pull-up; RFEYDA, spanish judo federation.

## Introduction

During the last decade, Heart Rate Variability (HRV), analyzed both in time and spectral domains, has been widely used as a non-invasive marker of that ANS regulation of HR dynamics after exercise. Several studies have actually used it to explore post exercise parasympathetic reactivation and evaluate the influence of exercise duration and intensity.<sup>1-9</sup> In this context, the nonlinear approaches have shown to be a way to gain additional information regarding cardiac autonomic modulation after exercise.<sup>3,10-12</sup> Unlike time domain and spectral measures, nonlinear methods detect qualitative rather than quantitative changes in HR dynamics.<sup>13,14</sup> Fractal analysis, through Detrended fluctuation analysis (DFA) technique, could be considered as a modification of spectral analysis; but unlike the latter, the former is thought not to be polluted by changes in the external environment,<sup>15-17</sup> what makes it especially suitable for assessing HR dynamics in field-based situations. However, only a pair of studies regarding post exercise HRV recovery had previously focused on

gender comparison.<sup>18,19</sup> Brown and Brown<sup>18</sup> found no significant differences in any frequency domain HRV index after a VO<sub>2</sub>max test to exhaustion in a trained Master athlete's sample. On the contrary, very recently Mendonca et al.<sup>19</sup> in a non-athletes sample, showed that cardiac autonomic function of women is greater affected by supra maximal exercise than that of men.

Concerning autonomic regulation following judo-type efforts, Cottin et al.<sup>20</sup> compared a judo combat versus an incremental cycloergometric exercise, but they evaluated the exercise-phase and not the recovery-phase. And very recently, some studies with judokas have shown that HRV and more specifically the non-linear analyses, are suitable to reflect the autonomic impairment following supra maximal efforts, with lower DFA in those judokas who were able to perform better (i.e. more repetitions in a supra maximal test).<sup>2,3</sup> However, none of these studies has focused in gender differences regarding HR dynamics and autonomic recovery following judo supra maximal efforts. Even more, little research has been conducted with regard to gender differences in judo performance in an integrative test, with high demands on specific explosive-strength endurance and technical stability under fatigue.

We need to deepen on the relationship among specific technical skills and conditional capacities with regard to these HR dynamics during recovery from judo combat effort since judo competition is made of both isometric and acyclic dynamic efforts and a great neuromuscular and cardiovascular demand on the upper body.<sup>21-28</sup> We also need to widen our knowledge about gender differences in physical fitness and specific stamina. Therefore, in order to improve

our understanding into the acute physiologic strain inherent with this type of exercise, the main purpose of this investigation was to characterize the recovery timeline of HR dynamics following a field-based judo test: the Blasco Specific Judo Test (BSJT),<sup>2,3,28,29</sup> using both linear and nonlinear HRV methods. We also aimed to verify whether gender could influence cardiac autonomic regulation in a highly trained judokas sample after a supra maximal protocol.

On the one hand, based on previous research regarding supra maximal interval protocols,<sup>1,8,10,12,30</sup> we hypothesized that BSJT should lead to a severe perturbation of ANS regulation of HR despite its relatively short duration. On the other hand, although Mendonca et al.<sup>19</sup> have pointed out that DFA does not provide additional information about sexual dimorphisms (i.e., compare with conventional HRV techniques), we postulated that in the event of being gender differences in regard to their recovery ability, it would be only distinguishable by means of nonlinear methods of analysis (i.e., DFA).

## Materials and methods

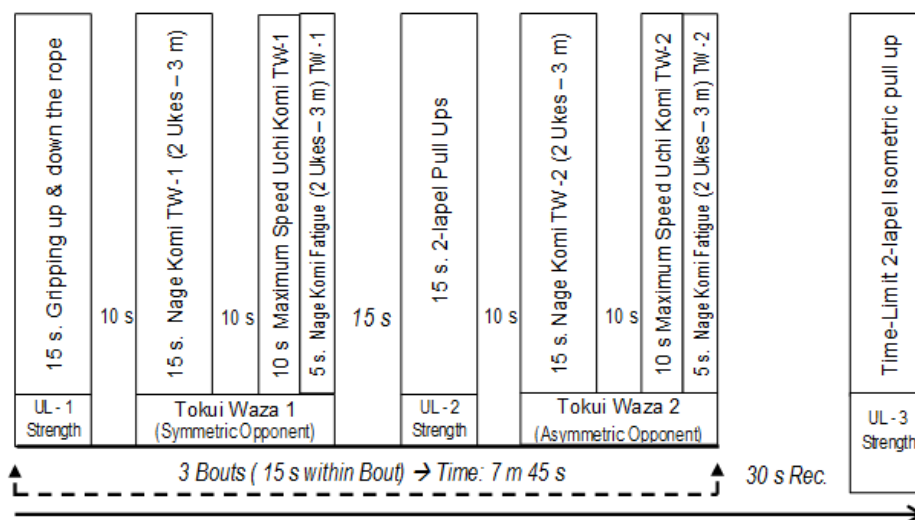
### Subjects

Forty-one judokas from the Spanish National Team participated in the study. As in Cottin et al.<sup>20</sup> study, data acquisition design posed a challenge. Actually, seventeen subjects were excluded from the analysis due to excessive number of artefacts in their HR recordings. The remaining sample (24 subjects ranging from all weight categories, 48 to >78kg in women and 60 to >100kg in men) consisted of 16 males and 8 females, 14 under-23 judokas and 10 junior judokas

(72.17±15.19kg, 24.40±0.97years). The study conformed to the Declaration of Helsinki and participants gave voluntary written consent to participate in the investigation, which was approved by the ethics committee of the University of Valencia. Data were collected during a National Team training camp held in the High-Performance Training Centre of Madrid (Spain).

### Blasco specific judo test

BSJT is aimed at reproducing both neuromuscular and energy demands of judo competition and verifying the performance of specific skills within a time structure similar to that of a contest. Briefly, BSJT comprises six 15-s exercise periods, separated by 10-s recovery periods and played for three consecutive bouts; and finishes with a larger 30-s recovery period followed by a “time-limit” isometric pull-up. Accordingly, total duration of the test varies from 8 to 9 minutes; depending on each subject’s ability to maintain the above-mentioned isometric pull-up. Performance in BSJT could be then assessed considering either total number of repetitions played during the test (raw BSJT total score) or number of repetitions played in each of the six drills employed; whereas final “time-limit” isometric pull-up is retained for further analysis (see statistical analysis section) but not included in raw BSJT total score. Because of the way BSJT assess some specific judo drills (i.e., Nage-komi, Uchi komi) (Figure 1) three judokas of similar body weights are needed to perform the test: 1 participant (tori) is evaluated and 2 other individuals receive throws (uke). Time structure and drills employed in the test were previously described in detail elsewhere<sup>28</sup> (Figure 1).



**Figure 1** Experimental procedures in the Blasco Specific Judo Test (BSJT).

UL, upper-limb; TW, tokui waza (Tori’s Best Technique); Uchi Komi, Skill consisting in the non-throwing repetition of a technique; Nage Komi, skill consisting in throwing the opponent

### HRV data acquisition and treatment

Prior to the beginning of the test, an electrode transmitter belt (T61, Polar Electro, Kempele, Finland) was fitted to the chest of each subject after application of conductive gel, as recommended by the manufacturer. A Polar RS800 HR monitor set to RR interval mode (Polar Electro, Kempele, Finland), was used to continuously record beat-to-beat HR.<sup>31,32</sup> To prevent the electrode from coming unstuck, transmitter belt was firmly held by adjusting a sticky bandage around the thorax. Similarly, HR monitor was attached to the judogi using an ad hoc handmade device. As soon as the test was finished (<5

s), subjects sat passively on a chair placed adjacent to the tatame. Unlike some recent investigations,<sup>8,10,19</sup> since the study was conducted in the field and we did not want to interfere individuals’ ability or strategy to recover themselves from the test, respiratory rate was not controlled.<sup>33–35</sup>

Data were transferred to Polar Pro Trainer 5 software (Polar Electro, Kempele, Finland) through an infrared interface and each downloaded R-R interval file was then exported as a .txt file and further analyzed by means of Kubios HRV Analysis Software 2.0 (The Biomedical Signal and Medical Imaging Analysis Group, Department of Applied

Physics, University of Kuopio, Finland). The whole analysis process was carried out by the same researcher to ensure consistency. After proper filtering and correction, time domain and spectral analysis were performed on the last 5 min of the 10-min recovery period to insure stability of the data, as widely recommended.

For the time domain, the standard deviation of normal R-R intervals (SDNN) and the root-mean-square difference of successive normal R-R intervals (rMSSD) were calculated. Prior to power frequency analysis, R-R data were detrended<sup>36</sup> and resampled at 4 Hz. The Fast Fourier Transform spectrum was then calculated using a Welch's periodogram method. Low frequency power (LF, 0.04-0.15 Hz), high frequency power (HF, 0.15-1 Hz) and total power (TP, 0.04-1 Hz) were calculated as integrals of the respective power spectral density curve. As in recent studies, the frequency limit of 1.0 Hz was chosen to include the respiratory frequency to the analysis.<sup>4,5,7</sup> LF/HF ratio was also retained for statistical analysis.

Besides time domain and spectral analysis, DFA technique was applied to the R-R interval data in order to quantify self-similarity correlations. A detailed description of this technique has previously been provided by Peng et al.<sup>14</sup> Briefly, the root-mean-square fluctuation of the integrated and detrended data are measured in observation windows of different sizes and then plotted against the size of the window on a log-log scale. The result of this calculation is the scaling exponent  $\alpha$ , which represents the slope of this line, which relates (log) fluctuation to (log) windows size. Typically, in DFA the correlations are divided into short-term and long-term fluctuations. Based on previous research<sup>19,37</sup> and because of our relatively short recording time, we decided to utilize the short-term (4 to 16 beats) scaling exponent ( $\alpha_1$ ) to analyze our R-R interval data. Distance scores from the optimal value of  $\alpha_1=1$  (i.e.  $|1-\alpha_1|$ ), as proposed by Millar et al.<sup>37</sup> were also calculated.

### Statistical analyses

All statistical analyses were carried out using the Statistical Package for the Social Sciences software (SPSS version 15.0, SPSS Inc., Chicago, USA). The distribution of each variable was examined with the Kolmogorov-Smirnov normality test. When data were skewed, as

it was the case for spectral measures, data were transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. Therefore, TP, HF and LF variables will henceforth be referred as lnTP, lnHF and lnLF, respectively.

Total repetitions completed for each of the six drills employed in the BSJT and time of the final isometric pull-up was converted into t-scores, enabling parametric statistical analysis and added up to generate a BSJT total score. Then, gender differences in total and partial (i.e., each of the six drills employed in the test) scores were evaluated using a Student's t test model for two samples of unequal variance. Homogeneity of variance was verified by a Levene test. Effect size (ES) was used to estimate the magnitude of the difference. As proposed by Cohen,<sup>38</sup> the difference was considered small when  $ES \leq 0.2$ , moderate when  $ES \leq 0.5$  and eventually great when  $ES > 0.8$ .

A one-way ANCOVA was employed to elucidate differences in HRV indices and  $\alpha_1$  between males and females, using BSJT total score as co-variable so as group differences were adjusted for the test performance. Pearson's correlation analysis was performed between all measures. The magnitudes of correlations were defined according to Cohen,<sup>38</sup> whereby correlations  $>0.5$  are considered large, 0.3-0.5 are considered moderate and 0.1-0.3 are considered small. A P value of  $<0.05$  was considered statistically significant. Data are presented as means and standard deviations ( $\pm$ SD).

## Results

### BSJT performance and gender

Total repetitions performed for every drill assessed in the test and total BSJT score are presented in Table 1. Regarding partial drills, only at gripping up and down the rope, men performed significantly more repetitions than women (males  $43.31 \pm 6.61$ , females  $35.38 \pm 9.53$ ;  $p=0.026$ ;  $d=0.97$ ). Notwithstanding 2-lapel pull-ups and fatigue Nage-komi displayed a large effect size ( $d>0.8$ ) and a tendency towards statistical significance ( $p<0.1$ ). Respecting BSJT total score, Student's t test revealed a large and significant effect size group difference (males  $311.96 \pm 34.72$ , females  $276.09 \pm 44.14$ ;  $p=0.040$ ;  $d=0.90$ ) (Table 1).

**Table 1** Repetitions performed in each partial drill and total Blasco Specific Judo Test (BSJT) score

	Men		Women		p	d
	raw score	T-score	saw score	T-score		
Gripping up & down (repetitions)	43.31 $\pm$ 6.61	53.15 $\pm$ 7.86	35.38 $\pm$ 9.53	43.71 $\pm$ 11.33	0.026	0.97
2-lapel pull ups (repetitions)	21.38 $\pm$ 3.50	53.16 $\pm$ 6.03	15.88 $\pm$ 7.83	43.68 $\pm$ 13.49	0.093	0.96
Nage-komi (repetitions)	40.38 $\pm$ 3.77	51.82 $\pm$ 10.30	38.38 $\pm$ 3.25	46.36 $\pm$ 8.86	0.215	0.57
Fatigue Nage-komi (repetitions)	13.63 $\pm$ 1.82	52.64 $\pm$ 9.61	12.13 $\pm$ 1.73	44.72 $\pm$ 9.11	0.066	0.84
Uchi komi (repetitions)	53.38 $\pm$ 9.71	48.88 $\pm$ 11.91	56.13 $\pm$ 3.27	52.25 $\pm$ 4.01	0.448	0.38
Final isometric pull up (seconds)	18.88 $\pm$ 9.43	52.32 $\pm$ 10.49	12.63 $\pm$ 6.74	45.37 $\pm$ 7.49	0.11	0.76
Total BSJT score	172.06 $\pm$ 16.09	311.96 $\pm$ 34.72	157.88 $\pm$ 21.46	276.09 $\pm$ 44.14	0.04	0.9

Values are provided as means $\pm$ SD.

For clarity of the data presentation: results are provided in both raw and transformed scores (t-scores). Raw Total BSJT score does not include time achieved in the final isometric pull up. Student's t test was conducted only on the transformed scores.  $P < 0.05$ .

### Correlations between linear HRV measures, nonlinear measures and BSJT performance

LF/HF ratio displayed a positive large significant correlation with  $\alpha 1$  ( $r=0.540$ ;  $p<0.01$ ). A similar relationship was found between LF/HF ratio and  $|1-\alpha 1|$  index ( $r=0.655$ ;  $p<0.01$ ). Regarding the relationship

between post-exercise HR dynamics and BSJT performance, only a significant, moderate, negative correlation between final isometric pull-up drill and both  $\ln TP$  ( $r=-0.457$ ;  $p<0.05$ ) and  $\ln LF$  ( $r=-0.496$ ;  $p<0.05$ ) was found. No other significant correlations were found. Results of the correlation analysis between linear and nonlinear HRV indices and BSJT performance can be viewed in Table 2.

**Table 2** Correlations between linear and nonlinear HRV indices (5 to 10 min of the recovery period) and BSJT partial drills and total score

	Sdnn	rmssd	lnTP	lnhf	lnlf	Lf/hf	$\alpha 1$	$ 1-\alpha 1 $
Gripping	-0:141	-0:227	-0:215	-0:220	-0:144	0:032	-0:093	0.0805556
2-lapel pull ups	-0:172	-0:124	-0:254	-0:096	-0:245	-0:228	-0:244	-0:090
Nage-Komi	-0:145	-0:199	-0:255	-0:202	-0:252	-0:058	0:084	0.1888889
Fatigue Nage-Komi	-0:157	-0:191	-0:224	-0:168	-0:213	-0:126	0:056	0:036
Speed Uchi Komi	-0:166	-0:286	-0:205	-0:353	-0:175	0.2152778	-0:008	0.2375
Time limit pull up	-0:382	-0:252	-0:457*	-0:278	-0:496*	-0:280	-0:251	-0:277
Total T-Score	-0:284	-0:312	-0:393	-0:322	-0:372	-0:086	-0:111	0:097

SDNN, standard deviation of R-R intervals; RMSSD, root-mean-square difference of successive R-R intervals; LNTP, total frequency power of R-R intervals; LNLF, low-frequency power of R-R intervals; LNHF, high-frequency power of R-R intervals; LNLF/HF, ratio of low-frequency to high-frequency power;  $\alpha 1$ , short-term fractal scaling exponent;  $|1-\alpha 1|$ , distance score from the optimal value of  $\alpha 1=1$ . \* $P<0.05$ .

### Heart rate dynamics following BSJT

Table 3 shows post exercise gender-specific results of linear and nonlinear (i.e.,  $\alpha 1$  and  $|1-\alpha 1|$ ) HRV indices. Non-significant gender differences were found in any time (SDNN, rMSSD) or frequency domain indices ( $\ln TP$ ,  $\ln LF$ ,  $\ln HF$ , LF/HF). The short-term scaling exponent ( $\alpha 1$ ) also failed to discriminate between males and females. Nevertheless, the  $|1-\alpha 1|$  index did show a significant group difference (males  $0.355\pm 0.199$ , females  $0.513\pm 0.252$ ;  $p<0.05$ ) (Table 3). Importantly, this  $\alpha 1$  was severely depressed during the test ( $0.412\pm 0.139$  and  $0.398\pm 0.075$  in men and women respectively), recovering up to  $1.142\pm 0.262$  and  $1.324\pm 0.237$  in the first 5 min of the recovery, and finally staying at  $1.279\pm 0.301$  and  $1.304\pm 0.508$ , always for men and women, in the five last minutes.

**Table 3** Linear and nonlinear HRV parameters during the recovery following BSJT

	Men	Women	P
SDNN (ms)	$6.29\pm 3.19$	$8.25\pm 5.35$	0.548
rMSSD (ms)	$4.45\pm 2.36$	$5.54\pm 3.94$	0.807
$\ln TP$ (ms <sup>2</sup> )	$3.41\pm 1.18$	$3.96\pm 0.74$	0.658
$\ln HF$ (ms <sup>2</sup> )	$2.84\pm 1.25$	$3.47\pm 0.82$	0.552
$\ln LF$ (ms <sup>2</sup> )	$1.97\pm 1.12$	$2.40\pm 0.94$	0.751
LF/HF	$3.28\pm 2.91$	$3.72\pm 2.76$	0.844
$\alpha 1$	$1.28\pm 0.30$	$1.30\pm 0.51$	0.94
$ 1-\alpha 1 $	$0.36\pm 0.20$	$0.51\pm 0.25$	0.046

SDNN, standard deviation of R-R intervals; RMSSD, root-mean-square difference of successive R-R intervals; LNTP, total frequency power of R-R intervals; LNLF, low-frequency power of R-R intervals; LNHF, high-frequency power of R-R intervals; LF/HF, ratio of low-frequency to high-frequency power;  $\alpha 1$ , short-term fractal scaling exponent;  $|1-\alpha 1|$ , distance score from the optimal value of  $\alpha 1=1$ .  $P<0.05$ .

### Discussion

A significant delay in parasympathetic reactivation has been observed following moderate to high intensity exercise when compared with that at a low to moderate intensity.<sup>6,7,39-41</sup> Conversely, exercise duration seems not to affect so much HR recovery dynamics;<sup>5,9</sup> just by increasing total time 4-fold or more we do find a significant change in parasympathetic reactivation.<sup>4</sup> When talking about supra maximal interval protocols, Buchheit et al.<sup>1</sup> showed a significant slower parasympathetic reactivation after a Repeated Sprint exercise compared with a continuous one of equivalent net caloric expenditure, concluding that anaerobic metabolism participation rather than energy expenditure modulates the level of post exercise parasympathetic reactivation. A similar depressed post exercise cardiac autonomic response has been reported by other authors using Wingate test<sup>8,10,12,19</sup> and Repeated Shuttle Sprint.<sup>30</sup> These results suggest that the depression of parasympathetic HRV indices appears to be a common response to anaerobic exercise, independently of muscular engagement. However, Heffernan et al.<sup>42</sup> utilizing sub maximal protocols (i.e., 3 sets of 10 repetitions of 9 exercises with 90s of rest between sets vs. 30 min of continuous upright stationary cycling at 65%  $VO_{2max}$ ), showed greater reductions in overall HRV after resistance exercise compared with endurance exercise. In fact, our group has already shown a big parasympathetic depression in HR dynamics during recovery from a supra maximal exercise with a great strength demand on upper-body muscles (i.e., a specific judo test).<sup>2,3</sup> Consequently, the present investigation contributes further to previous studies examining cardiac autonomic regulation after endurance-type supra maximal exercises (i.e., Wingate test, Repeated Sprint protocols) and extends our knowledge to complex efforts that integrate both specific endurance and strength requirements, now focusing in gender differences.<sup>7</sup>

In terms of linear HRV measures, our results (Table 3) are in agreement with previous studies on endurance-type supra maximal efforts, which showed greatly reduced vagal activity (as evidenced by poor values for rMSSD and  $\ln HF$ ). Notwithstanding, care should

be taken with the interpretation of our data, as our sample consisted of highly-trained judokas. Actually, all of them belonged to the Spanish National Team, either to Under-23 or Junior categories. To the best of our knowledge, only one study regarding post exercise HRV recovery had previously worked with a sample of similar level to ours.<sup>9</sup> Interestingly, Seiler et al.<sup>9</sup> reported that interval training (6 x 3 min with 2 min of active recovery) performed at 95-100%  $VO_{2max}$  was incapable of triggering a greater delay in parasympathetic reactivation among highly trained athletes, compared with training at lactate-threshold intensity. In our study, subjects underwent a single experimental condition (i.e., BSJT), which makes it difficult to draw a real comparison between post exercise HRV recovery following endurance-type efforts versus complex efforts. Notwithstanding, their post exercise cardiac autonomic regulation was severely depressed (Table 3); thus undoubtedly indicating that, despite their high level of training, BSJT induces them a great ANS disturbance. Judo is considered to elicit great amounts of stamina and muscular endurance. Upper limb work is achieved mainly through anaerobic metabolic pathways, due to a concomitant high demand on strength and speed. Technical and tactical performance largely depends on Rate of Force Development (RFD) and power capacities, in conjunction with isometric strength.<sup>21,28,43</sup> Hence, although Maximal Aerobic Power plays a part enabling the energetic demands of the contest as a whole; strength, technique and speed requirements focus fatigue in the neuromuscular system. Therefore, in line with Heffernan et al.<sup>42</sup> it could be suggested that even at high intensities, the greater the neuromuscular system participation, the greater the post exercise ANS disturbance.

Additionally, we found that  $\tau_{LPU}$  correlated significantly with both  $LnTP$  and  $LnLF$ ; however, no significant correlation was found between  $\tau_{LPU}$  and  $LnHF$ . Two important findings may be highlighted at this point. On the one hand, the similar relationship of LF and TP recovery patterns with  $\tau_{LPU}$ . This phenomenon, as suggested by Kaikkonen et al.<sup>5</sup> may be due to the fact that TP during recovery from high-intensity exercise, in contrast to rest, consists mostly of low frequency variation; thus indicating overall changes in cardiac autonomic regulation rather than changes in vagal modulation. Moreover, as a matter of fact, HF may be affected by the occurrence of non-neural oscillations, such as the mechanical effect of breathing.<sup>44-46</sup> On the other hand, isometric pull-up key role in modulating postexercise HRV could be explained according to biphasic pattern observed by Maciel et al.<sup>47</sup> in HR dynamics response to isometric exercise. Briefly, at the beginning of the contraction, the fast elevation in HR occurs due to vagal withdrawal; whereas by continuing with the isometric exercise, after 10 s or even a little before at maximum intensities (our subjects kept up  $\tau_{LPU}$  for  $16.79 \pm 8.99$ s), sympathetic contribution starts to dominate after vagal withdrawal gradually increasing tachycardia. Therefore, this final augmented sympathetic discharge may explain the lower overall HRV indices ( $LnTP$  and  $LnLF$ ) found in those subjects who had performed a longer isometric pull-up.

In an attempt to gain a further qualitative understanding of the effects of a supra maximal judo-based effort on post exercise cardiac autonomic regulation, we compared men to women on their nonlinear HR dynamics (i.e.,  $\alpha_1$ ) response to the BSJT. No significant differences were found either in time and spectral domain measures, or in  $\alpha_1$ . However, it is well-known that fractal scaling properties have a bi-directional pattern of responses, which may mask detection of significant modulations.<sup>48</sup> Values approaching  $\sim 0.5$  reflect an increasingly random signal (i.e., white noise), while those nearing  $\sim$

1.5 reflect a strongly correlated signal (i.e., Brownian noise).<sup>14</sup> Under normal conditions a value of 1, reflecting fractal-like behaviour or balance between complete randomness and predictability (i.e., pink noise), is associated with healthy HR dynamics.<sup>48,49</sup> In order to address that bi-directional nature of DFA, we calculated distance scores from the optimal value of  $\alpha_1=1$ , as proposed by Millar et al.<sup>37</sup> and found a significantly lower value in men compared to women (Table 3).

It is widely known that one of the main differences between men and women sport performance is related to RFD and speed capacities, even in such a specific skill as gripping.<sup>50,51</sup> In judo competition, athletes spend most of the time ( $51 \pm 11\%$ ) trying to perform this action;<sup>24</sup> accordingly, BSJT contains a specific upper-limb strength drill based on that skill: gripping up & down the rope. Interestingly, men performed significantly more repetitions than women ( $p=0.026$ ;  $d=0.97$ ) in that task. At the same time, the 2-lapel pull-ups drill, which is also considerably related to gripping ability, showed a large effect size and a clear tendency to significance ( $p<0.1$ ). Furthermore, Fatigue Nage Komi, used to assess the remaining specific explosive strength when lactate production and anaerobic contribution are largest (Figure 1), displayed a similar behavior to that described for gripping up & down the rope and 2-lapel pull-ups drills. Consequently, total BSJT score also showed a large and significant gender difference. Therefore, differences between males and females in the capacity to perform tasks where RFD and speed are decisive, may have explained gender differences in  $\alpha_1$  during recovery. Because of that, in the ANOVA analysis group differences were adjusted for the test performance by using BSJT total score as co-variable, thus controlling this possible confounding effect.

Two important findings may be highlighted at this point. On the one hand, our results are in line with previous investigations suggesting better accuracy of nonlinear methods to detect subtle changes in HR behaviour; especially when HR is recorded in field-based situations where respiratory rate is not usually fixed and/or total spectral power of HR signal is low.<sup>15,17,52,53</sup> Interestingly, LF/HF ratio despite keeping a large and significant correlation with  $|1-\alpha_1|$  index, failed to reveal a significant gender difference during post-exercise recovery. This is in disagreement with Mendonca et al.<sup>19</sup> who postulated that DFA does not provide additional information regarding gender differences, compared with HRV power spectral analysis. On the other hand, an improved ability of men (i.e., compared to women) to recover themselves from a supra maximal effort may be suggested, as they are capable of achieving a better balance between complete randomness and predictability. These results do reinforce those obtained by Mendonca et al.<sup>19</sup> who have recently reported a better, although not-statistically significant,  $|1-\alpha_1|$  index in men compared to women (males  $0.28 \pm 0.04$ , females  $0.37 \pm 0.06$ ). Their not-statistically significant differences may be explained by the dose-response relationship with respect to altering cardiac autonomic control proposed by Millar et al.<sup>12</sup> as they used a 30-s protocol and BSJT lasts between 8 and 9 minutes. Moreover, when examining relative values (i.e., mean change from rest to early recovery), Mendonca et al.<sup>19</sup> did find that the increase in  $\alpha_1$  was significantly of greater proportion in female participants. Because of the characteristics of our sample (elite athletes usually have a rather inflexible time schedule) we unfortunately could not assess HR dynamics at rest.

## Conclusion

In summary, the major outcomes of this investigation were:

- A. 10 min following a supra maximal specific judo test cardiac autonomic regulation remains severely depressed, even in elite athletes. The greater strength demand on upper-limb muscles, compared to supra maximal efforts more often employed (i.e. Wingate test, Repeated Sprint protocols, etc.), could be responsible for such a large disturbance in cardiac autonomic regulation following BSJT. Our results would thus suggest that complex efforts, requiring for optimal functioning of neuromuscular system, cause a delayed post-exercise parasympathetic reactivation. Moreover, isometric strength requirements seem to play a critical role in modulating that delay. At the same time,
- B. Gender differences regarding post exercise HR dynamics found in our study extends Mendonca et al.<sup>19</sup> results to elite athletes population and further reinforces the postulate that men, compared to women, possess an improved ability to recover themselves from supra maximal efforts.
- C. Nonlinear methods prove superior to detect subtler changes in HR behaviour, especially when HR is recorded in field-based situations where respiratory rate is not usually controlled and/or total spectral power of HR signal is low, as it is the case for recovery from supra maximal exercises. Nevertheless, the findings of this study are preliminary and further research is required to clarify differences in parasympathetic reactivation and overall HRV following complex efforts that integrate both specific endurance and strength requirements, compared to endurance and resistance-type efforts.

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## Conflict of interest

The present manuscript has been partially supported by the Spanish Judo Federation (RFEJYDA), who has consent to publish the results. Moreover, this research complies with the Spanish laws and the Declaration of Helsinki and has been approved by the ethics committee of the University of Valencia.

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