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Effects of Acute High-intensity Exercise on Heart Rate Variability Following Rapid Weight Loss in Elite Wrestlers

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Abstract

Investigating how the autonomic functions of the heart are affected during rapid weight loss practices is extremely important for athletes' health. This study aimed to investigate how rapid weight loss (3–5%) affects heart rate variability (HRV) in elite wrestlers. Twelve elite freestyle male wrestlers (mean age: 19.8±3.3 years; height: 172.4±4.0 cm; body weight: 76.9±11.6 kg) participated in this study. Body composition and HRV measurements were taken before the wrestlers started to lose weight (14 days before the competition) and after 3–5% of their body weight was lost. HRV measurements in the time domain—RR (time between RR intervals—ms), SDNN (standard deviation of NN intervals), and RMSSD (root mean square of consecutive RR interval differences)—and power values in the high-frequency (HF) and low-frequency (LF) bands and the LF/HF ratio were taken at rest, after warm-up, and during high-intensity exercise and recovery using a Polar Vantage V2 monitor and H10 sensor. The data were analyzed via repeated-measures analysis of variance (ANOVA). The analyses were performed with the statistical program SPSS version 28.0 (IBM Corp., Armonk, NY, USA). Comparisons of differences were performed via two-way ANOVA (2 sessions × 4 times). Bonferroni correction was used for pairwise comparisons. The significance level was set at $p<0.05$. No significant changes were observed in the HRV time-domain parameters after short-term rapid weight loss ($p>0.05$). However, a significant increase in the LF/HF ratio was detected post-RWL ($p<0.05$). Rapid weight loss of up to 5% of total body weight in combat sports did not significantly affect HRV time-domain parameters. A modest increase in the LF/HF ratio was observed, suggesting a potential shift in autonomic balance, although the clinical implications of this finding remain uncertain.

Keywords: Rapid weight loss, elite wrestlers, heart rate variability, dehydration

1. Introduction

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Rapid weight loss (RWL) has attracted the attention of both the American College of Sports Medicine and the American Medical Association, both of which have expressed opposition to this practice [1,2]. RWL is widely practiced in combat sports before competition, with strategies such as partial or complete food deprivation and dehydration until the target weight is reached [3]. Athletes often severely restrict food and fluid intake in the last three weeks—or even less—before competition and may resort to strenuous exercise in warm clothing, sauna use, and the use of pharmacologic agents such as diuretics [4,5]. In particular, excessive fluid loss can result in decreased plasma volumes, increased heart rates, and decreased arteriovenous oxygen differences during exercise [6,7], which negatively affect performance and can be hazardous to health [8]. In addition, excessive fluid loss has negative effects, such as changes in the central nervous system, increases in core temperatures, greater reliance on muscle glycogen, and changes in metabolic function [9,10,11]. In addition, higher levels of dehydration in combat sport athletes are associated with lower power output and reduced contraction velocity [12]. Dehydrated wrestlers may have greater levels of muscle damage, as measured via creatine kinase [13]. Dehydration also significantly impairs cognitive function measures (such as attention, motor coordination, and reaction time) [14]. Dehydration can impact various bodily functions, potentially increasing the risk of injury by affecting an athlete's ability to react to an opponent's movement [15]. However, evidence that rapid weight loss impairs aerobic or anaerobic function is inconsistent [16]. Although the adverse health effects of rapid weight loss have been well documented, the prevalence of aggressive and harmful weight-cutting methods, such as wrestling, judo, and boxing, remains notably high in combat sports [10,17,18]. Several studies have reported that rapid weight loss is prevalent in 60–90% of wrestlers participating in international competitions [19,20,21,22,23,24]. Rapid weight loss practices are not limited to only male athletes but also female athletes [25].

In the literature, numerous studies have investigated the effects of rapid weight loss on various variables, such as flexibility, aerobic and anaerobic power, athlete psychology, injury risk, body composition, and energy expenditure in wrestlers [15,26,27,28]. Some studies have shown that dehydration impairs aerobic and anaerobic performance, skill-based performance, thermoregulation and cardiovascular stress [27,29]. Some authors have also reported an increase in the resting HR when RWL is used [30,31]. To date, only one study [32] has directly examined HRV responses to RWL in combat athletes. In the present study, eight male combat athletes (62.5% mixed martial arts [MMAs], 25% Brazilian Jiu-Jitsu, and 12.55% Muay Thai) were evaluated via two measurements taken 14 days before and 1 day before the official weigh-in [32]. HRV analysis renders it possible to measure autonomic nervous system modulation under different physiological conditions and reveals oscillations in the intervals between consecutive heartbeats, reflecting the influence of the autonomic nervous system on the sinus node [33]. For the cardiovascular system to rapidly adapt to sudden physical and psychological challenges, time differences occur rhythmically [34,35]. These time differences are referred to as HRVs, and HRV analysis is a noninvasive method used to monitor the autonomic functions of the heart [33,36,37]. The time-domain parameters of HRVs have recently received greater attention than traditional spectral analyses because of their superior reliability and ability to capture assessments over short periods of time [38,39]. Although frequency-domain indices such as the LF/HF ratio are widely reported, their physiological interpretation—particularly as a marker of sympathovagal balance—remains controversial. Therefore, in the present study, time-domain HRV parameters were considered the primary indicators of autonomic modulation, whereas LF/HF-related findings were interpreted cautiously and as secondary outcomes.

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The fact that wrestling is a weight-class sport requires wrestlers to maintain optimal body composition. For this reason, wrestlers attempt to increase their lean mass ratio in the long term while trying to decrease their fat ratio and total body weight [40]. However, rapid weight loss practices in a short period of 2–3 weeks before competition are thought to be aimed mostly at fluid loss, and the autonomic functions of the heart are negatively affected by excessive fluid loss. In a previous study, rapid weight loss was reported to cause dehydration and impaired heart rate recovery in highly trained judo athletes [41]. In the literature, the effects of rapid weight loss on physiological characteristics have mostly been examined. However, the control mechanism in the body is the central nervous system (CNS), which affects all the physiological characteristics of the body. Despite extensive documentation on the negative impacts of RWL on physical performance, few studies have directly explored autonomic function and HRV under post-RWL high-intensity exercise conditions in elite wrestlers [15]. Addressing this gap in research is essential for refining cardiovascular health recommendations for combat athletes. Given this information, the aim of this study was to investigate the effects of high-intensity exercise on HRV parameters before and after rapid weight loss in elite wrestlers. We hypothesized that RWL would increase sympathetic modulation, as reflected by elevated LF/HF ratios.

2. Materials and Methods

2.1. Participants

Twelve elite freestyle male wrestlers aged 18–30 years participated in our study (mean age: 19.83±3.27 years; height: 172.41±4.05 cm; body weight: 76.85±11.61 kg; body mass index (BMI): 25.85±3.62 kg/m2). Given the limited availability of prior research directly examining HRV responses to rapid weight loss in elite wrestlers, a formal effect-size-based power calculation specific to this population and intervention could not be reliably performed. Therefore, this study is presented as an exploratory pilot investigation. The sample of twelve elite freestyle male wrestlers was determined based on feasibility and comparison with previous exploratory studies in similar populations [42,43]. As such, the results should be interpreted as preliminary and hypothesis-generating, pending confirmation in larger studies. The inclusion criteria were as follows: i) being a freestyle wrestler, ii) having an active wrestling license for at least 5 years, iii) having a National Athlete Certificate of at least level C (having represented Turkey in at least one international senior wrestling tournament organized by the United World Wrestling), iv) having trained regularly for the last 12 months, and v) not having had any injury in the last 6 months. The exclusion criteria were as follows: i) any cardiovascular health condition, ii) use of drugs or substances that affect the respiratory or cardiovascular system, iii) use of ergogenic supplements (e.g., creatine), and iv) history of RWL cycles within the last year. A history of RWL cycling may blunt autonomic responses due to previous adaptations to weight cycling [44]. The selection of elite wrestlers with international experience and without recent RWL cycles was intended to control for previous adaptations to weight cycling, which could blunt autonomic responses; this enhances our study's validity. However, it should be noted that by excluding athletes with a history of RWL cycles within the last 12 months, the sample may not fully represent chronic or habitual weight-cutters who could exhibit different autonomic responses. Consequently, caution is warranted when generalizing these findings to all RWL athletes. The participants were instructed to follow exercise-induced sweating and reduced food and fluid intake, while avoiding diuretics, saunas, and similar practices. However, individual strategies (e.g., daily training volume, exact dietary and fluid intake, and sleep patterns) were not formally logged, and adherence

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to instructions was not objectively verified. Therefore, the exact “dose” of rapid weight loss may have varied between athletes, which should be considered when interpreting the physiological responses observed in this study. Additionally, the participants were asked not to consume alcohol, caffeine, etc., in the last 24 hours before the tests.

2.2. Procedure

The wrestlers’ body composition and HRV measurements were obtained before they began to lose weight (14 days before the competition weigh-in, pre-RWL) and after they lost 3–5% of their body weight (post-RWL). Since post-RWL measurements were taken before the official weigh-in, the wrestlers' food and fluid intake remained restricted. Body composition measurements were taken at 08:30 in the morning. After the body composition measurements, the participants rested in the supine position until 09:00. HRV measurements were recorded at 09:00 in the morning, at rest, and in the supine position for 10 min. The supine position provides more reliable results for HRV measurements than the sitting or standing positions do [45]. The participants were instructed to breathe normally, remain relaxed, avoid movement, and not speak during the recording. Considering that food intake may affect autonomic activity, all participants were asked to refrain from eating in the last two hours before data collection and from consuming caffeine in the last 6 hours [46]. After 10 min of resting (morning) HRV measurement (Time 1/T1), the participants were given 10 min to warm. After the warm-up, a total of 28 min 30 s HRV measurements were taken during a 6 min passive rest session (Time 2/T2), a 6 min 30 s treadmill exercise session (3 min running + 30 s rest + 3 min running) (Time 3/T3), and a 6 min passive rest session (Time 4/T4) (Figure 1).

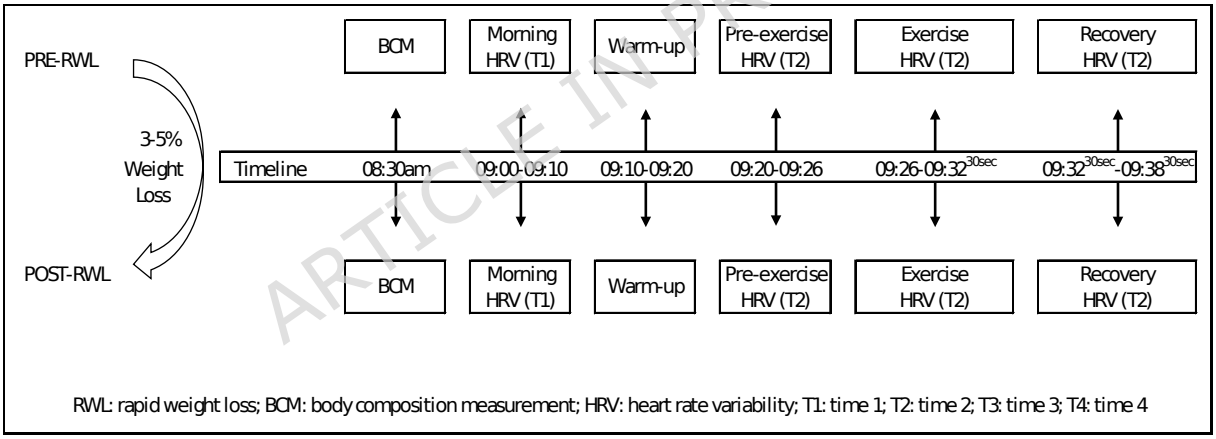


Figure 1. Experimental design.

The participants performed a running exercise on a treadmill at 75–80% of their maximum heart rate for 2 × 3 minutes (the duration of a wrestling match) at 30-second intervals. The intensity of exercise is determined by the percentage of heart rate reserve (HRR) calculated via the Karvonen formula: target heart rate (HR) = ([maximum heart rate (HRmax) – resting HR] × % target) + resting HR [47]. The resting heart rate was determined separately at T1 before RWL and at T1 after RWL. 75–80% of maximal heart rate (HRmax) reflects a high-intensity effort; however, it may still be below the peak intensities typically observed during wrestling matches (90–95% of HRmax). This intensity was selected to standardize effort across participants and to ensure safety during repeated HRV measurements under rapid weight loss conditions. It should be noted that higher, competition-simulated intensities may elicit greater sympathetic activation and potentially more pronounced changes in HRV parameters. Therefore, the results observed here may

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underestimate autonomic responses that occur at maximal competition intensity, and future studies should consider using intensity protocols closer to real match conditions.

2.3. Body composition

The body composition of the participants was determined via the bioimpedance (BIA) method (Tanita BC-418MA, Tanita Europe B.V. Hoogoorddreef 56E1101 BE Amsterdam, Holland). This device is capable of determining total body weight, fat percentage, fat content, lean weight, and total body fluid, as well as calculating BMI. Although BIA is a convenient and non-invasive method for estimating body composition, including total body water (TBW), it is highly sensitive to acute fluid shifts and may not reliably detect subtle changes in hydration status [40,48]. Therefore, TBW values obtained via BIA should be considered a crude, descriptive measure rather than a primary indicator of hydration. Future studies should incorporate more direct hydration markers, such as urine or plasma osmolality or urine specific gravity, to more accurately assess fluid status.

2.4. Heart rate variability

The participants' heart rate variability was measured with a Polar Vantage V2 monitor and a Polar H10 heart rate sensor (Kempele, Finland). Nuuttila et al. [49] confirmed that the Polar V2 device provides similar results to ECG. The Polar V2 monitor and H10 chest strap can be used for RR interval assessments during intense activities, although there may be a potential deviation from the value measured with a standard ECG [50]. The heart rate variability dataset was processed using Kubios HRV 2.0. The RR interval series were sampled at 1000 Hz using the Polar Vantage V2 and H10 sensor. Artifacts and ectopic beats were identified and corrected automatically using Kubios with a very low correction threshold (<5%). Across all participants and time points, the median percentage of corrected beats was 1.5% (ranging from <0.1% to 4.6%). No participants or measurement segments were excluded due to excessive artifacts, as all correction percentages remained below the pre-specified threshold. Ectopic or missed beats were replaced via the Kubios interpolation algorithm to ensure continuity of the RR interval series. In the time domain, the RR (time between RR intervals—ms), SDNN (standard deviation of NN intervals), and RMSSD (root mean square of consecutive RR interval differences) were calculated. In the frequency domain, the nonparametric fast Fourier transform (FFT) algorithm was used. It should be noted that FFT assumes signal stationarity, which may not be fully met during dynamic exercise or transitions between exercise and rest (e.g., T3). Therefore, frequency-domain metrics obtained during T3 are presented for descriptive purposes only, and primary inferences regarding sympathovagal balance focus on the more stable rest phases (T1, T2, and T4). Total power (TP) and power in the high-frequency (HF) and low-frequency (LF) bands (TP: 0–0.4 Hz; LF: 0.04–0.15 Hz; HF: 0.15–0.4 Hz) were calculated in absolute units (ms^2), with the LF/HF ratio used cautiously as an indicator of sympathovagal balance. Additionally, normalized units (nu) were calculated for descriptive purposes and are presented in Figure 4 to visually highlight relative changes in sympathetic and parasympathetic modulation. Statistical inferences reported in Table 2 are based on absolute units (ms^2), ensuring consistency of primary analyses. The selected HRV parameters (SDNN and RMSSD) reflect the time-domain indices of overall HRV, whereas the LF and HF components represent sympathetic and parasympathetic modulation, respectively. The LF/HF ratio, despite ongoing debate regarding its physiological significance, is commonly used as an indicator of sympathovagal balance and autonomic strain, which is particularly relevant for understanding cardiovascular stress in high-intensity athletic contexts [52,53].

2.5. Statistical analysis

The data were analyzed via SPSS version 28.0 (IBM Corp., Armonk, NY, USA). Descriptive parameters are presented as the means and standard deviations. The

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normality of all variables was analyzed with the Shapiro–Wilk test. Two-way repeated-measures ANOVA (2 sessions × 4 time points) was used to examine HRV parameters. Given the exploratory nature of this study and multiple HRV endpoints, we pre-specified **resting RMSSD at T1** as the primary outcome measure, while all other HRV variables (mean RR, SDNN, LF, HF, LF/HF) were treated as secondary or exploratory outcomes. Pairwise comparisons were adjusted via Bonferroni correction; however, due to the exploratory nature of secondary outcomes, p-values should be interpreted cautiously, particularly for LF/HF where the session effect approached the significance threshold (p=0.050). The sphericity assumption was tested via Mauchly's test. In cases where this assumption was violated, the Greenhouse–Geisser correction was applied. To provide additional information about the magnitude and direction of change, the absolute differences (Δ) between the two time points were also calculated via group averages. The significance level was set at $p<0.05$. The partial eta squared (ηp2) of repeated-measures ANOVA and Cohen's d for pairwise differences were used to calculate the ES. The magnitudes of the ES were classified as trivial (0.0–0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), or very large (>2.0).

3. Results

Table 1 shows the means and standard deviations of the descriptive characteristics of the athletes before and after weight loss. In Table 2, the main effects of exercise and the main effects of time and exercise × time interactions were analyzed with respect to the mean RR, SDNN, RMSSD, LF, HF, and LF/HF parameters, and pairwise comparisons were performed.

Table 1. Descriptive characteristics of participants before and after rapid weight loss (n=12).

	Pre-RWL	**Post-RWL**	
Variables	**Mean±*SD***	**Mean±*SD***	**p**
Weight (kg)	76.85±11.61	74.11±11.41*	0.001
BMI (kg/m^2)	25.85±3.62	24.83±3.68*	0.001
Body fat (%)	12.24±5.48	10.18±5.38*	0.034
Fat mass (kg)	9.81±5.46	7.94±4.93*	0.015
FFM (kg)	67.06±7.96	66.53±8.84	0.240
TBW (kg)	49.09±5.83	48.73±6.48	0.259

* p<0.05. BMI: Body mass index; % percentage; FFM: fat-free mass; TBW: total body water; RWL: rapid weight loss.

As shown in Table 1, body weight, BMI, body fat percentage, and fat mass decreased significantly ($p<0.05$), whereas fat-free mass and total body water did not differ significantly ($p>0.05$).

Table 2. Comparison of HRV parameters before and after rapid weight loss (two-way repeated-measures ANOVA).

Variables	**Exercise**	**Morning (T1)**	**Preexercise (T2)**	**Exercise (T3)**	**Recovery (T4)**	**Main Effect of Time**	**Main Effect of Exercise**	**Time x Exercise Interactions**
		Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	***(η_p^2/p)***	***(η_p^2/p)***	***(η_p^2/p)***
Mean RR	Pre-RWL	931.74±141.52	801.54±107.04*	394.51±26.21*#	681.74±78.33*#	0.945 t t	.000	.103 t t
	Post-RWL	968.01±105.23	803.51±149.05*	387.88±36.93*#	644.71±119.66*#	**0.001**	.965	.304

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SDNN	Pre-RWL	63.49±8.15	58.17±11.85	9.36 ±7.62*#	32.61±11.31*#	0.927 ^{tt} **0.001**	.153 .186	.073 .466
	Post-RWL	64.42±13.11	52.31±11.42	7.67 ±7.85*#	25.59 ±15.08*#			
RMSSD	Pre-RWL	67.44±16.13	58.61±15.44	8.95±10.08*#	22.84±9.21*#	0.903 ^{tt} **0.001**	.074 .368	.144 .157
	Post-RWL	70.21±11.03	47.61±16.71*	8.21±9.19*#	19.29±15.68*#			
LF	Pre-RWL	56.57±12.26	68.46±13.98	68.86±17.31	81.73±9.16*#	0.551 ^{t} **0.001**	1.148 ^{tt} .195	.032 .783
	Post-RWL	57.13±11.18	72.16±11.41	76.46±16.16*	83.98±13.77*			
HF	Pre-RWL	43.34±12.22	31.51±13.94	31.08±17.26	18.22±9.15*#	0.551 ^{t} **0.001**	.149 .192	.032 .778
	Post-RWL	42.79±11.19	27.76±11.38	23.46±16.06*	15.98±13.77*			
LF/HF	Pre-RWL	1.69±0.82	3.17±2.10	3.03±1.73	5.28±4.52	0.562 ^{t} **0.001**	.307 ^{t} .050	.118 .240
	Post-RWL	1.47±0.81	3.15±1.50	5.45±4.27*	7.47±3.41*#			

*: $p<0.05$ relative to morning values; #: $p<0.05$ relative to preexercise values; η_p^2: effect size (effect size: ^{t} small effect, ^{tt} intermediate effect, ^{ttt} large effect); RR: time between RR intervals in milliseconds; SDNN: standard deviation of all normal-to-normal RR intervals; RMSSD: root mean square of successive RR interval differences; LF: low frequency; HF: high frequency; LF/HF: ratio between LF and HF; T1: time 1; T2: time 2; T3: time 3; T4: time 4.

The main effect of time on the mean RR according to post hoc pairwise comparisons revealed statistically significant differences between morning and preexercise ($p<0.003$, $\Delta = 147.36$, $d = 1.56$); morning and exercise ($p<0.001$, $\Delta = 558.69$, $d = 7.10$); morning and recovery ($p<0.001$, $\Delta = 286.65$, $d = 3.58$); preexercise and exercise ($p<0.001$, $\Delta = 411.33$, $d = 5.11$); preexercise and recovery ($p<0.001$, $\Delta = 139.29$, $d = 1.55$); and exercise and recovery ($p<0.001$, $\Delta = 272.04$, $d = 4.23$) periods.

Post hoc pairwise comparisons of the main effect of time in the SDNN revealed statistically significant differences between morning and exercise ($p<0.001$, $\Delta = 55.44$, $d = 8.47$), morning and recovery ($p<0.001$, $\Delta = 34.86$, $d = 3.90$), preexercise and exercise ($p<0.001$, $\Delta = 46.73$, $d = 7.47$), preexercise and recovery ($p<0.001$, $\Delta = 26.14$, $d = 2.84$), and exercise and recovery ($p<0.001$, $\Delta = -20.59$, $d = 2.84$) periods.

Post hoc pairwise comparisons of the main effect of time on the RMSSD revealed statistically significant differences between the morning and exercise ($p<0.001$, $\Delta = 60.24$, $d = 7.31$), morning and recovery ($p<0.001$, $\Delta = 47.76$, $d = 4.97$), preexercise and exercise ($p<0.001$, $\Delta = 44.53$, $d = 4.33$), preexercise and recovery ($p<0.001$, $\Delta = 32.04$, $d = 2.72$), and exercise and recovery ($p<0.015$, $\Delta = 12.49$, $d = 1.55$) periods.

In post hoc pairwise comparisons of the main effect of time in LF, statistically significant differences were found between the morning and exercise ($p<0.002$, $\Delta = 15.81$, $d = 1.52$), morning and recovery ($p<0.001$, $\Delta = 26.01$, $d = 2.91$), and preexercise and recovery ($p<0.001$, $\Delta = 12.54$, $d = 1.28$) periods.

Post hoc Bonferroni pairwise comparisons of the main effect of time in HF revealed statistically significant differences between the morning and exercise ($p<0.002$, $\Delta = 15.79$, $d = 1.53$), morning and recovery ($p<0.001$, $\Delta = 25.96$, $d = 2.91$), and preexercise and recovery ($p<0.008$, $\Delta = 12.53$, $d = 1.30$) periods.

Bonferroni pairwise comparisons of the main effect of time on LF/HF revealed statistically significant differences between the morning and exercise ($p<0.003$, $\Delta = 2.66$, $d = 1.88$), morning and recovery ($p<0.002$, $\Delta = 4.80$, $d = 2.65$), and preexercise and recovery ($p<0.033$, $\Delta = 3.21$, $d = 1.46$) periods.

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A statistically significant difference was observed in the LF/HF ratio regarding the main effect of exercise (p=0.050). No significant differences were found in the main effect of exercise or in interactions for any of the other parameters (p>0.05).

The exercise × time interactions of the HRV parameters are shown, with the mean RR and SDNN data presented in Figure 2, the RMSSD and LF/HF ratios in Figure 3, and LF and HF in Figure 4.

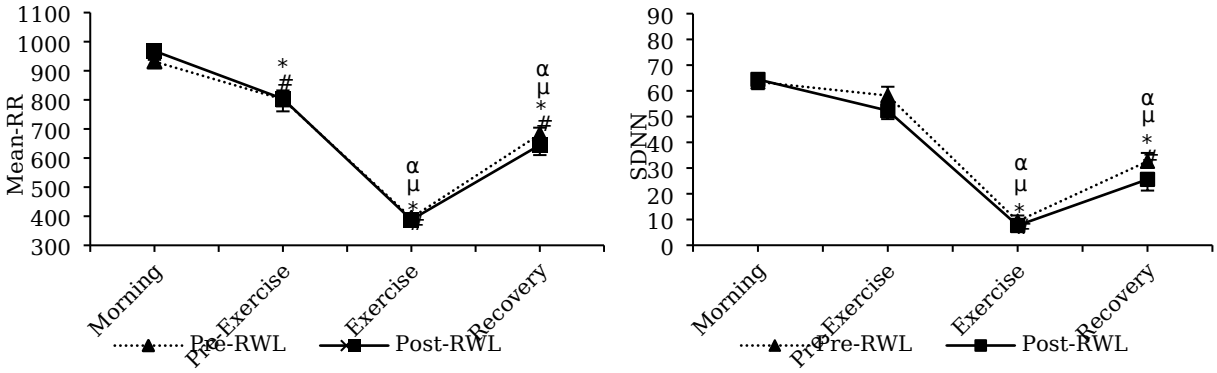


Figure 2. The values of Mean-RR and SDNN across time points. Data are presented as Mean ± SD. # Significant difference between Post-RWL and Morning (p<0.05). * Significant difference between Pre-RWL and Morning (p<0.05). μ Significant difference between Post-RWL and Pre-exercise (p<0.05). α Significant difference between Pre-RWL and Pre-exercise (p<0.05).

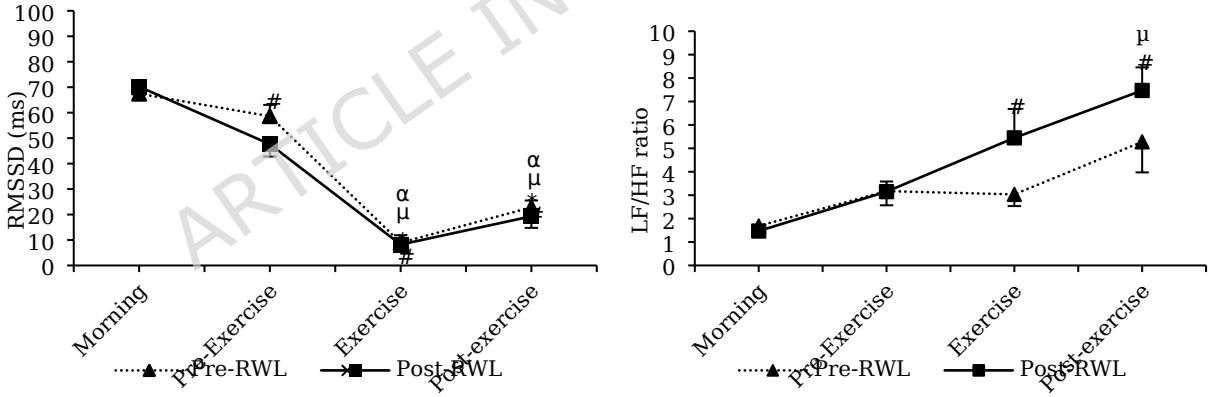


Figure 3. The values of RMSSD and LF/HF ratio across time points. Data are presented as Mean ± SD. # Significant difference between Post-RWL and Morning (p<0.05). * Significant difference between Pre-RWL and Morning (p<0.05). μ Significant difference between Post-RWL and Pre-exercise (p<0.05). α Significant difference between Pre-RWL and Pre-exercise (p<0.05).

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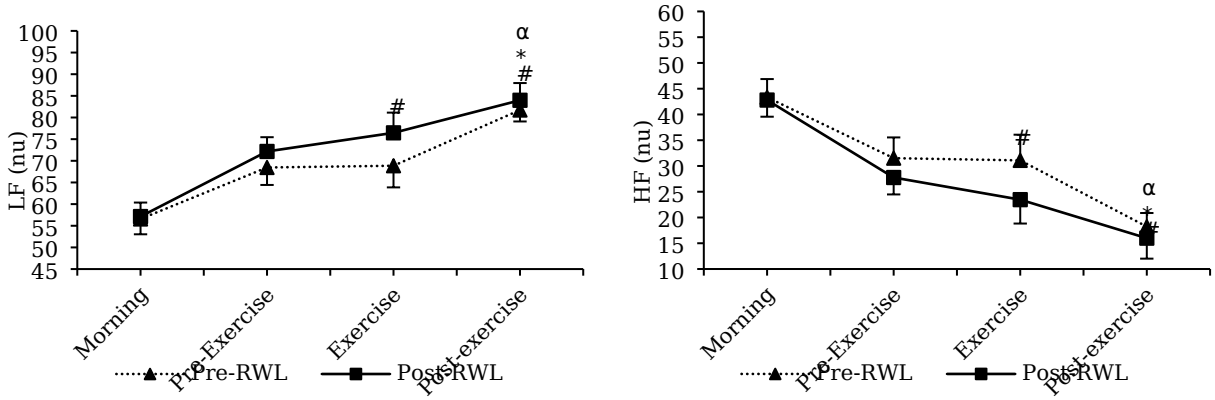


Figure 4. Changes in LF and HF power expressed in normalized units (nu) for descriptive visualization. Statistical analyses were conducted using absolute units (ms^2) as reported in Table 2. The values of LF and HF across time points. Data are presented as Mean ± SD. # Significant difference between Post-RWL and Morning ($p<0.05$). * Significant difference between Pre-RWL and Morning ($p<0.05$). μ Significant difference between Post-RWL and Pre-exercise ($p<0.05$). α Significant difference between Pre-RWL and Pre-exercise ($p<0.05$).

4. Discussion

In the present study, to examine the effects of rapid weight loss on the autonomic nervous system, HRV was measured at four time points (morning, preexercise, exercise, and postexercise), as were body composition measurements before and after rapid weight loss. To our knowledge, this study is the first to examine HRV changes during exercise at 75–80% of the maximum heart rate before and after weight loss in elite wrestlers. The most important finding of our study was that rapid weight loss had no effect on the HRV time-domain parameters (mean RR, SDNN, and RMSSD). In other words, the HRV time-domain parameters measured in the morning, preexercise, exercise, and postexercise periods before and after rapid weight loss were similar. These findings suggest that an RWL of <5% did not significantly alter the HRV time-domain parameters in this sample. In a previous study, RWL was reported to cause dehydration and impair heart rate recovery in highly trained judo athletes [41]. Another study reported that RWL decreased aerobic and anaerobic power in elite judo and wrestlers [26]. A study investigating the relationship between injury and RWL in wrestlers reported that RWL caused injuries in elite wrestlers [54]. In contrast to the studies in the literature, no negative rapid weight loss effect was observed in this study. Although studies in the literature have generally examined the effects of rapid weight loss on physical characteristics, it should not be overlooked that the autonomic nervous system is linked to many other physiological systems [55,56,57]. Only one study in the literature has examined the effects of rapid weight loss on HRV. Similar to our study, this study reported that rapid weight loss had no effect on HRV time-domain parameters; however, rapid weight loss resulted in high sympathetic modulation [32].

Although a statistically significant increase in the LF/HF ratio was observed following rapid weight loss, this finding should be interpreted with caution given the ongoing debate regarding the physiological meaning of LF/HF and the fact that these values were obtained from the T3 exercise period, which involved non-stationary RR interval data. Importantly, LF/HF was a secondary outcome and the p-value (0.050) is fragile in the context of multiple comparisons. The primary outcome (resting RMSSD at T1) showed no significant change, reinforcing the conservative interpretation that rapid weight loss up to 5% did not meaningfully alter HRV time-domain parameters. All other HRV endpoints are considered

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exploratory. Nevertheless, the observed increase in the LF/HF ratio following RWL may suggest a potential enhancement in sympathetic modulation [53]. A study conducted with combat athletes reported that rapid weight loss caused a significant increase in cardiac sympathetic modulation (LF) according to measurements taken 14 days before and 1 day before the competition [32]. Another study has shown that when rapid weight loss occurs, there are a number of physiological changes, such as lower myocardial efficiency, maximal oxygen consumption, and damage to the thermoregulation process [58]. Such changes indicate an increase in heart rate to compensate for the decreased stroke volume, a phenomenon that occurs to maintain cardiac output during fixed work intensity [59]. Autonomic modulation is important in heart rate control, and rapid changes in these parameters can contribute to cardiovascular disorders [60]. These studies are similar to the present study in terms of the effects of RWL on autonomic modulation. Considering both the findings of the present study and the existing literature, it is suggested that athletes undergoing rapid weight loss may be at an increased risk of cardiovascular complications. The LF/HF ratio provides information on sympathovagal balance; however, its interpretation as an indicator of cardiovascular risk remains controversial [34] and should be approached cautiously, particularly in small, exploratory studies. Given that athletes in weight-class sports may repeatedly engage in rapid weight loss practices, careful monitoring of this condition is recommended.

Previous studies have shown that a decrease in total body weight after rapid weight loss is usually due to fluid loss [22,32,61]. Many studies have also reported that fluid loss during weight loss negatively affects the cardiovascular system and that hypohydration results in a decrease in cardiac efficiency [48]. A study with judo athletes reported that athletes did not rehydrate sufficiently after 15 hours of recovery despite a weight gain of up to 5% [41]. In the present study, no significant difference was observed in the total body water before and after rapid weight loss, whereas the body fat percentage decreased significantly (Table 1). Given the sensitivity of BIA to acute fluid shifts, this should be interpreted cautiously. The absence of a TBW change does not definitively indicate that athletes were fully euhydrated, and more precise measures of hydration would be needed to confirm this. The absence of detectable changes in total body water as measured by BIA should be interpreted cautiously. Given the limitations of BIA in capturing acute fluid shifts, meaningful changes in hydration cannot be excluded. Therefore, any potential link between hydration status and the minimal HRV changes observed in this sample remains speculative.

Although psychological adaptation to the adverse effects of rapid weight loss has been reported in some studies [44,62], it has also been documented that chronic rapid weight fluctuations do not provide protection against these negative effects [63]. Although not directly addressed in the current study, chronic rapid weight loss cycles are known to be common among elite wrestlers. Although similar HRV parameters were observed before and after rapid weight loss in this study, the current research does not provide data on the athletes’ long-term history of rapid weight loss. Therefore, the notion that these findings reflect a physiological adaptation to weight cycling remains speculative and should be considered as a hypothesis for future investigations.

The wrestlers’ mean body weight at baseline was 76.85 kg, which decreased to 74.11 kg following rapid weight loss, corresponding to an average reduction of 3.57% of total body weight. Some previous studies reported that rapid weight loss does not affect high-intensity performance in male athletes when it is approximately 5% or less of the baseline body weight [44,62,64]. On the basis of studies in the literature, rapid weight loss of up to 5% of total body weight is considered unlikely to adversely affect athletes' performance, physiological characteristics, or the central nervous system, which serves as the control

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mechanism. Although performance was not measured in the present study, previous literature suggests that rapid weight loss of up to 5% may have minimal effects on physiological characteristics in male athletes [44,62,64]. Accordingly, the lack of substantial changes in HRV observed here is consistent with these findings, but no conclusions regarding actual performance can be drawn from the current data. However, numerous harmful aspects of the physical, physiological, and psychological consequences of RWL have been documented [5].

As mentioned above, this study's limitations include the fact that rapid weight loss was limited to 3–5% of body weight, the possibility that the participating wrestlers may have physiologically adapted to weight cycling, and the lack of change in total body fluid. Another limitation is that while the magnitude of rapid weight loss was controlled, the exact rate and timing of weight reduction were not fully documented for each athlete. Variations in the speed of weight loss could influence the degree of autonomic stress, and future studies should aim to monitor daily weight changes to better understand the relationship between the rate of RWL and physiological responses. A further limitation of the study is that total body water was estimated using BIA, which is sensitive to acute fluid shifts and may not accurately reflect true hydration status. While BIA provides convenient body composition metrics, its sensitivity to hydraversion shifts necessitates cautious interpretation. Given the limitations of BIA in discriminating total body water, future studies may benefit from dual-energy X-ray absorptiometry (DEXA) or isotope dilution techniques to increase sensitivity when assessing body composition changes in elite athletes [40,48]. Future studies should also incorporate more direct measures, such as urine or plasma osmolality, to more accurately evaluate fluid balance. Future studies should be conducted with athletes who lose more than 5% of their total body weight within a short period (1–2 weeks) prior to official weighing. Subsequent research should extend beyond male wrestlers to examine sex-specific autonomic responses in female combat athletes, addressing possible differences in sympathetic reactivity under RWL and exercise stressors [61]. On the other hand, our exclusion of athletes who had engaged in rapid weight loss within the past year limits the external validity of the study. As a result, the findings may not fully generalize to chronic or habitual weight-cutting athletes, who are often at higher risk for adverse physiological effects. Additionally, we acknowledge that the relatively small sample size limits statistical power, and the present findings should be considered preliminary. Future studies with larger cohorts are needed to confirm these results and provide more robust effect-size estimates for HRV responses to rapid weight loss. A further limitation of the study is that the specific rapid weight loss strategies employed by each athlete were not documented in detail, and adherence to instructions was not objectively verified. Consequently, variations in training, nutrition, fluid intake, and sleep may have influenced the observed autonomic responses, highlighting the exploratory nature of these findings.

5. Conclusions

The results of the present study suggest that rapid weight loss (up to 5%) does not significantly affect HRV time-domain parameters but may increase sympathetic modulation. Elevated sympathetic modulation should be carefully considered, as it may carry potential cardiovascular implications for athletes engaged in rapid weight loss cycles. While RWL <5% may not impair HRV, its potential health risks warrant further investigation before considering regulatory implications.

6. Patents

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Author Contribution Statements: Conceptualization: Y.Y., R.A., and A.M.R.; methodology, all authors; formal analysis, A.K.G. and G.C.R.; investigation, Y.Y. and C.R.; writing—original draft preparation, Y.Y., R.Y.S., G.C.R. and A.M.R; writing—review and editing, all authors; supervision, R.A., J.F.L.G., and A.M.R; project administration, Y.Y., R.Y.S. and R.A. All the authors have read and agreed to the published version of the manuscript.

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