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Cognitive and Technical-Tactical Adaptations to Rapid Weight Loss in Elite Judoka

Perceptual and Motor Skills

2025, Vol. 0(0) 1–20

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Abstract

Purpose: This study investigates the effects of moderate ($\leq 5\%$) and high ($> 5\%$) weight loss (WL) on physiological recovery, cognitive performance, self-control, and technical-tactical performance in elite judo athletes during international competitions.

Methods: Twenty elite athletes (age: 20.6 ± 2.2 years; body mass: 72.3 ± 14.4 kg; height: 1.73 ± 0.09 m) were assessed during a 10-day period leading up to competition. Body mass, heart rate variability (HRV) at rest, cognitive performance, and technical-tactical performance were examined. Athletes were categorized into moderate (MWLG, $n = 9$) and high (HWLG, $n = 11$) weight-loss groups. Statistical analyses included repeated measures ANOVA and correlation tests.

Results: Both groups showed significant body mass reduction (MWLG: mean: $3.0 \pm 2.0\%$; HWLG: mean: $6.8 \pm 1.5\%$), with moderate to strong correlations between body mass reduction and increased response times on Flanker task ($r = 0.52-0.61$, $p < 0.05$). HRV indices remained stable, reflecting athletes' physiological resilience across the pre-

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competition period. Importantly, no significant differences were observed between groups in technical-tactical performance, self-control and inhibitory control.

Conclusion: WL was moderately associated with delayed response times on an inhibitory control task, indicating a change in cognitive strategy. These findings emphasize the need for integrated strategies combining weight management, recovery protocols, and cognitive training, as the observed associations between WL and cognitive response times may influence decision-making processes without directly impairing technical-tactical performance.

Keywords

weight management strategies, execution function, combat sports, decision-making

Introduction

AQ3 Weight loss (WL) is a common strategy among combat sport athletes (Zhong et al., 2025), including judo athletes, who often manipulate body mass to compete in specific weight categories (Artioli, Gualano, et al., 2010; Zhong et al., 2024). This process involves substantial reductions in body mass within a short period, followed by rapid recovery post weigh-in via rehydration and food intake (Artioli, Iglesias, et al., 2010). In judo, current competition rules allow that the body mass be up to 5% above the category limit during the re-weighing process on competition day, indirectly encouraging athletes to adopt at least this magnitude of weight loss (dos Santos et al., 2023). Understanding how such reductions and subsequent recovery affect performance is crucial for optimizing competitive readiness.

While post weigh-in recovery (weight gain, WG) has often been used as an indirect measure of the initial body mass reduction (Reale et al., 2016), this oversimplifies the variability in recovery efficiency and its implications for performance (Matthews et al., 2019). Evidence suggests that WL of up to 5%, combined with adequate recovery time, does not impair athletic performance (Artioli, Iglesias, et al., 2010; Reale et al., 2016), but may affect high-intensity repeated efforts (Brechney et al., 2022). This threshold has been widely considered manageable due to its minimal impact on strength, power, and cardiovascular function, provided athletes adhere to effective recovery protocols (Brechney et al., 2022).

Despite several studies investigating the effects of WL on various parameters, gaps remain regarding its impact on cardiovascular function, particularly heart rate variability (HRV), a marker of stress and recovery balance (Ceylan et al., 2022). Research shows that WL combined with high-intensity training impaired heart rate recovery in wrestlers (Roklicer et al., 2022) and induced dehydration-related autonomic dysregulation in judo athletes (Ceylan et al., 2022). As HRV reflects autonomic nervous system responses to stress (Shaffer & Ginsberg, 2017), it provides a valuable tool to assess the physiological adaptation to WL and its potential effects on performance (Plews et al., 2013).

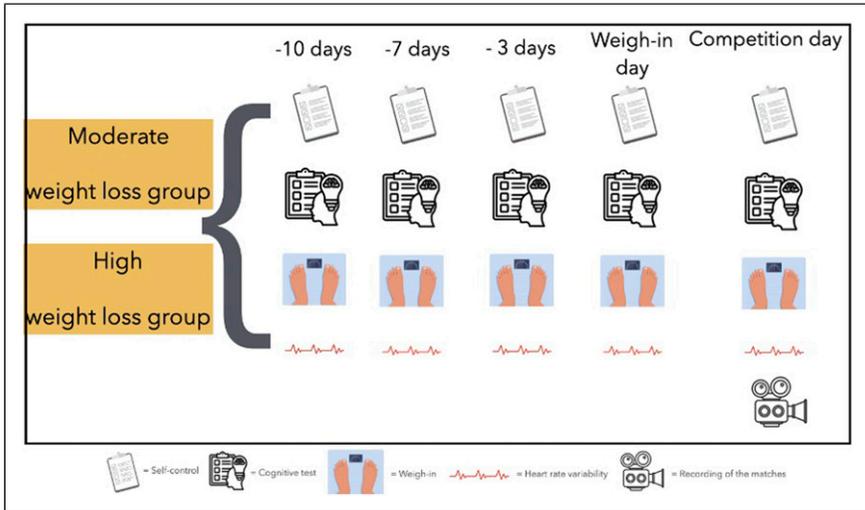


Figure 1. Experimental Design of the Study. The Days are Relative to the Weigh-In Day

The cognitive requirements of WL also warrant additional consideration. Throughout the weight loss process, athletes must monitor and control their behaviors, especially their eating habits, heavily relying on self-discipline. On a cognitive level, the inhibitory aspect of executive function is a key component underlying this ability (Miyake & Friedman, 2012). Specifically, cognitive inhibition refers to the ability to suppress negative feelings, thoughts and emotions and to resist distractions (Hofmann et al., 2012). In the context of judo, improved inhibitory control observed in athletes suggests that executive function is frequently engaged during performance (Ludyga et al., 2021). During WL, the prolonged demands for self-control may lead to cognitive depletion, which in turn can impair inhibitory control, decrease confidence, and compromise decision-making abilities, potentially affecting performance during crucial competition phases (Graham et al., 2017; Lakicevic et al., 2020).

Thus, the objective of the present study was to compare the effects of moderate weight loss ($\leq 5\%$; MWLG) and high weight loss ($> 5\%$; HWLG) on body mass variations, inhibitory control, physiological responses, and performance in elite judo athletes. We hypothesized that the HWLG would exhibit greater impairments in cognitive, physiological, and technical-tactical performance compared to the MWLG.

Methods

Sample

Twenty elite-level judoka athletes (mean age: 20.6 ± 2.2 years; body mass: 72.3 ± 14.4 kg; height: 1.73 ± 0.09 m) were recruited for this study, after the exclusion of two athletes. Athletes were recruited via direct contact with their coach. Participants were

required to meet the following inclusion criteria: (i) being active competition in national or international tournaments; (ii) having a minimum of six years of training experience and two years of competition experience; and (iii) being black belt. Two athletes were excluded from the final analysis: one due to missing data and another who did not complete the weight-cutting process. Therefore, they were not included in the prevalence calculation or subsequent analyses. This study was approved by the Ethics Committee of (64061822.8.0000.5391), and all participants provided written informed consent prior to participation.

Experimental Design

Data were collected during two international-level judo competitions that took place between May and June 2024, ensuring that all measurements were performed using the same methods and at standardized times. Both competitions featured athletes competing in standardized weight categories (as per International Judo Federation [IJF] regulations), and these events were held over two days (first day: weigh-in; second day: competition). The study employed a repeated-measures design to evaluate the effects of body mass changes over time and their interaction with groups categorized by WL magnitude (Figure 1). Athletes were divided into two groups: those who reduced their body mass by less than 5% of their baseline (MWLG: mean age: 19.7 ± 2.1 years; body mass: 68.1 ± 14.3 kg) and those who reduced by more than 5% (HWLG: mean age: 21.4 ± 2.2 years; body mass: 75.7 ± 14.1 kg). No significant differences were observed between MWLG and HWLG for age ($t = 1.74$; $P = 0.099$) or body mass ($t = 1.19$; $P = 0.249$). This grouping criteria was based on the official judo rules, which allow athletes to weigh up to 5% above their category's upper limit during the random weigh-in on competition day. Furthermore, previous research has shown that reducing body mass by up to 5%, followed by adequate recovery, does not impair judo performance (Artioli, Iglesias, et al., 2010; Brechney et al., 2022; Reale et al., 2018).

The primary outcome was body mass change relative to the upper limit of the athlete's weight categories. Secondary outcomes included heart rate variability (HRV), psychological performance, and technical-tactical performance. Participants followed their usual training and weight management routines. Data collection was divided into baseline (−10 days before weigh-in) and competition related phases (−7 days weigh-in, −3 days weigh-in, weigh-in day and competition day), always at the same time. In addition, all assessments were performed by the same researcher.

Body Mass

Body mass measured at five time points (10, 7, and 3 days before weigh-in, weigh-in day, and competition day) using a calibrated digital scale (Tanita TBC-300, Tokyo, Japan, precision: 0.1 kg).

Heart Rate Variability

HRV was measured using a validated mobile application, Elite HRV smartphone application (v3.8, EliteHRV, LLC, San Diego, CA, USA), designed for short-term HRV analysis. To ensure data reliability, all athletes underwent two familiarization sessions with the HRV measurement protocol. During these sessions, they were instructed on the proper use of the application and the chest strap heart rate monitor (Polar H10, Polar Electro Oy, Kempele, Finland). HRV measurements were conducted upon waking up, under resting conditions. Participants were instructed to lie down in a supine position and refrain from any movement or conversation during the 5-min recording period. This duration was chosen to capture baseline autonomic activity, as morning measurements are less likely to be influenced by external stressors. The application recorded the exact time of each measurement, ensuring adherence to the standardized measurement window. Data consistency was further validated by excluding two recordings that were taken outside this time frame. The primary HRV indices analyzed included the root mean square of successive differences (RMSSD) to mean R-R interval (MRR) ratio and the low frequency/high frequency (LF/HF) ratio, which are commonly used to assess autonomic nervous system activity (Shaffer & Ginsberg, 2017). Following data collection, HRV data were processed using Kubios HRV Software (version 4.0, Kubios Oy), a specialized tool for advanced HRV analysis, which offers precise and reliable processing of time-domain and frequency-domain HRV indices (Tarvainen et al., 2014).

Self-Control

Self-control levels reported by participants were assessed using a seven-point Likert scale, spanning from 1 (“not true at all”) to 7 (“completely true”). The assessment utilized a concise five-item adaptation, yielding an alpha coefficient of .71, exemplified by statements such as “I feel like my willpower is gone”, as suggested by Lindner et al. (2019). This short-form scale was developed from the State Self-Control Capacity Scale, as referenced in Bertrams et al. (2011), and was specifically created for use in repeated assessments to track changes in self-control over time. Research has shown the instrument to be a valid measure across different age groups, encompassing children, teenagers, and adults (Lindner et al., 2019). Scores that are higher suggest a greater feeling of self-control depletion.

Cognitive Aspects

Cognitive performance was assessed using a modified version of the Flanker task, which measures inhibitory control, and administered via the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA, USA). Subjects were shown a central target stimulus (an arrow) amidst flanking arrows and were instructed to press a button corresponding to its direction. The flanking arrows pointed in the same or different direction on congruent and incongruent trials, respectively. Both trials were randomly distributed in equal proportions (Duckworth & Kern, 2011). The central stimulus was

visible for 120 ms after a fixation time that ranged between 700 and 1200 ms. Respondents had up to 1000 ms following stimulus onset to provide a response. Following the completion of practice trials, two blocks of 40 trials each were conducted by the participants. Accuracy and reaction times (on response-correct trials only) were calculated separately for congruent and incongruent trials.

Technical and Tactical Analysis

The technical and tactical aspects of performance were evaluated by examining video footage of competitive matches. Key variables were extracted for each sequence initiated by a *hajime* (start) command and ended by a *matte* (stop) command, based on established criteria (Agostinho & Franchini, 2021; de Camargo et al., 2019) and identified for the athletes. The analysis involved key aspects: determining match outcomes by identifying winners and losers based on the decisions of official referees and recording scores awarded during the match. The task was to count and categorize attacks conducted in both standing and groundwork positions, and to determine if these attacks yielded points. The orientation (forward/backward and right/left) properties of each attack sequence were assessed to better understand the directionality and strategy employed during combat. The combat phases consisted of measuring standing combat time, which involved engagement aimed at throws; total attack time, defined as the cumulative duration of all attack actions; total approach time, from the start signal until gripping; total gripping dispute time, measured from the onset of the grip until the execution of a technique; and groundwork combat time, from the start of ground engagement until a *matte* was given. In addition, there were feints, which are movements intended to provoke reactions from the opponent. Variables were derived by calculating the intensity ratio, which consisted of high-intensity actions (attacks, feints, grip disputes, and ground combat) divided by low-intensity actions (displacements without contact and pauses). The winning percentage was calculated by dividing the number of victories by the total number of matches disputed. The technical variation index was the ratio of side-directed attacks to the overall number of attacks. The attack scoring ratio represents the proportion of attacks that successfully earned points relative to the total number of attacks performed. To determine the reliability, ten athletes were randomly chosen for reproducibility testing. The intraclass correlation coefficients for the different measures varied between 0.75 and 0.81, suggesting that the results were consistent and reliable.

Statistical Analyses

The normality of the data distribution was assessed and confirmed using the Shapiro-Wilk test. The data are presented as means with standard deviations, or medians with interquartile ranges (for technical and tactical aspects). Body mass changes, cognitive performance, and self-control were assessed using a two-way analysis of variance with repeated measures (factors: group - MWLG, HWLG; time -10 days, -7 days, -3 days, day 0, and +1 day), following the verification of

compound symmetry via the Mauchly test. The analysis aimed to determine the main effects of time and group on body mass, cognitive performance, and technical/tactical aspects. Additionally, the interaction between time and group was explored for all variables. When applicable, the Greenhouse-Geisser correction was applied. In case of significant findings, the Bonferroni test was used for post-hoc comparisons.

The magnitude of WL and WG was compared using an independent Student's *t*-test, while the technical and tactical aspects were compared using the Mann-Whitney *U* test. To evaluate the relationships between the variables, Pearson's correlation coefficient was calculated. Effect sizes for the analysis of variance were assessed using partial eta squared (η^2), where 0.01 was considered a small effect, 0.06 a medium effect, and 0.14 a large effect (Cohen, 1988; Lakens, 2013). The 95% confidence interval of the difference (95%CI_{diff}) was reported. For *t*-tests, effect sizes were evaluated using Cohen's *d*, with 0 to 0.19 representing a trivial effect, 0.20 to 0.49 a small effect, 0.50 to 0.79 a medium effect, and values greater than 0.80 a large effect (Cohen, 1988; Lakens, 2013). For technical and tactical analyses, effect size *R* was utilized ($R = Z/\sqrt{n}$), with 0.1 indicating a small effect, 0.3 a medium effect, and 0.5 a large effect (Morris & Richler, 2012). The strength of the correlation was classified according to the following scale: weak ($r < 0.3$), moderate ($r = 0.3-0.5$), strong ($r = 0.5-0.7$), and very strong ($r > 0.7$) (Cohen, 1988). A significance level of $p < 0.05$ was considered for all statistical tests.

Results

Body Mass Analysis

Regarding the prevalence of WL, 90.5% of athletes in the present study decreased their body mass prior to the competition. The magnitude of body mass reduction was $3.0 \pm 2.0\%$ for the MWLG and $6.8 \pm 1.5\%$ for the HWLG, while the magnitude of regain on the competition day (one day after weigh-in) was $2.0 \pm 1.5\%$ for the MWLG and $4.04 \pm 0.8\%$ for the HWLG. Medallists and non-medallists did not differ regarding the magnitude of body mass reduction ($P = 0.956$) and body mass regain ($P = 0.840$).

When analyzing the body mass variation over time (Figure 2), we found a main effect of time ($F_{3,20, 57.58} = 84.4; p < 0.001; \eta^2 = 0.824$ [large]) and an interaction effect (time \times group: $F_{3,20, 57.58} = 14.3; p < 0.001; \eta^2 = 0.443$ [large]). However, there was no difference between groups ($F_{1, 18} = 1.51; p = 0.235; \eta^2 = 0.077$ [medium]). For the effect of time, there were differences between the following points: -10 days vs. -3 days ($p < 0.001; 95\%CI_{diff} = 0.02; 2.20$ kg), -10 days vs. day 0 ($p < 0.001; 95\%CI_{diff} = 0.02; 6.56$), and -10 days vs. $+1$ day ($p < 0.001; 95\%CI_{diff} = 0.03; 2.33$); -7 days vs. -3 days ($p < 0.001; 95\%CI_{diff} = 0.10; 1.90$), -7 days vs. day 0 ($p < 0.001; 95\%CI_{diff} = 0.06; 6.10$), and -7 days vs. $+1$ day ($p < 0.001; 95\%CI_{diff} = 0.10; 1.97$); -3 days vs. day 0 ($p < 0.001; 95\%CI_{diff} = 0.18; 4.36$), and day 0 vs. $+1$ day ($p < 0.001; 95\%CI_{diff} = 0.11; 4.22$). The interaction effect demonstrated that the groups showed differences across time, however, comparisons between groups at each time point did not reveal any differences. Specifically, the MWLG group presented the

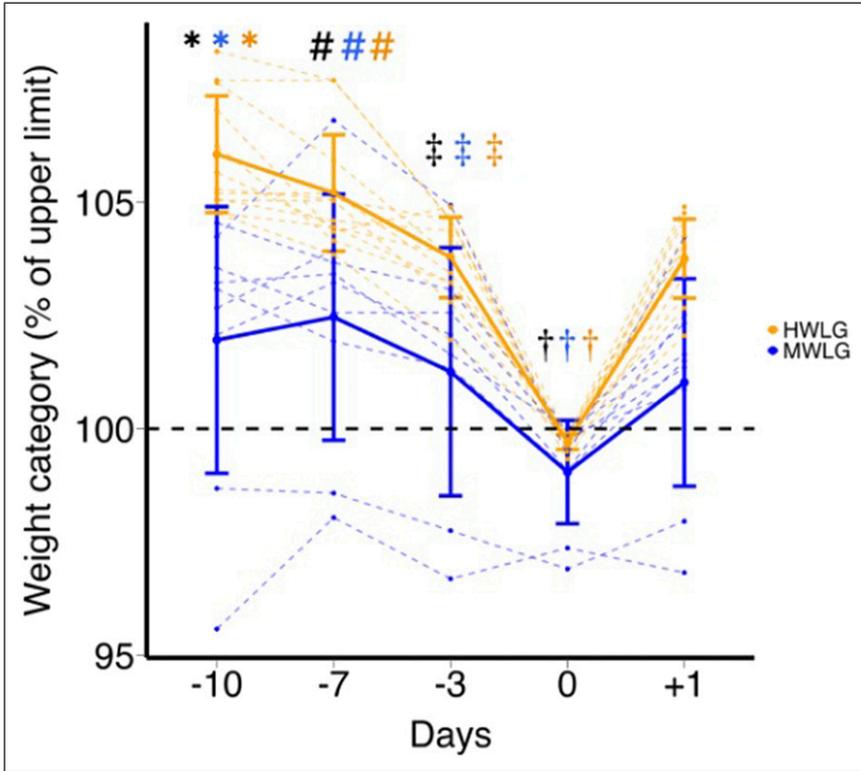


Figure 2. Body Mass Changes Relative to the Upper Limit of the Athletes' Weight Category From 10 days Prior to the Weigh-In up to the Competition. 0 = Weigh-In; HWLG = High Weight Loss Group; MWLG = Moderate Weight Loss Group. For the Time Effect (Black Symbols): *Indicates Difference Between -10 days vs. -3 days ($p < 0.001$), -10 days vs. +1 day ($p < 0.001$). #Indicates Difference Between -7 days vs. 3 days ($p < 0.001$), -7 days vs. Day 0 ($p < 0.001$), and -7 days vs. +1 day ($p < 0.001$). ‡ Indicates Difference Between -3 days vs. Day 0 ($p < 0.001$). † Indicates Difference Between Day 0 vs. +1 day ($p < 0.001$). For Variation Across Moments in the MWLG Group (Blue Symbols)* Indicates Difference Between -10 days vs. Day 0 ($p = 0.014$); # Indicates Difference Between -7 days vs. Day 0 ($p < 0.001$); ‡ Indicates Difference Between -3 days vs. Day 0 ($p = 0.005$); † Indicates Difference Between Day 0 vs. +1 day ($p < 0.001$). For Variation Across Moments in the HWLG Group (Orange Symbols)* Indicates Difference Between -10 days vs. -3 days ($p < 0.001$), -10 days vs. Day 0 ($p < 0.001$), and -10 days vs. +1 day ($p < 0.001$); # Indicates Difference Between -7 days vs. -3 days ($p = 0.002$), -7 days vs. Day 0 ($p < 0.001$), and -7 days vs. +1 day ($p = 0.015$). ‡ Indicates Difference Between -3 days vs. Day 0 ($p < 0.001$). † Indicates Difference Between Day 0 vs. +1 day ($p < 0.001$)

following differences: -10 days vs. day 0 ($p = 0.014$; $95\%CI_{diff} = 0.81; 3.60$), -7 days vs. day 0 ($p < 0.001$; $95\%CI_{diff} = 0.07; 4.14$), -3 days vs. day 0 ($p = 0.005$; $95\%CI_{diff} = 0.40; 2.80$), and day 0 vs. +1 day ($p < 0.001$; $95\%CI_{diff} = 0.97; 5.80$). The HWLG group presented the following differences: -10 days vs. -3 days ($p < 0.001$; $95\%CI_{diff} =$

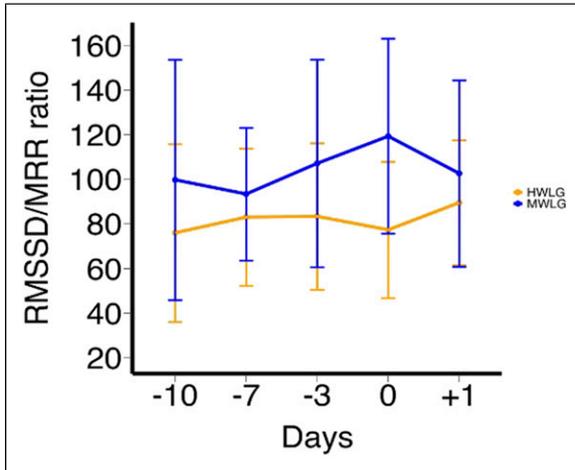


Figure 3. Frequency of Heart Rate Variability Recorded 10 Days, 7 Days, and 3 days before the Weigh-In, on the Weigh-In Day (0), and on the Competition Day (+1). Values are Presented as Mean and Standard Deviation; HWLG = High Weight Loss Group; MWLG = Moderate Weight Loss Group

0.81; 3.62), -10 days vs. day 0 ($p < 0.001$; 95%CI_{dif} = 0.78; 8.78), and -10 days vs. +1 day ($p < 0.001$; 95%CI_{dif} = 0.80; 3.60); -7 days vs. -3 days ($p = 0.002$; 95%CI_{dif} = 0.13; 2.23), -7 days vs. day 0 ($p < 0.001$; 95%CI_{dif} = 0.10; 8.10), and -7 days vs. +1 day ($p = 0.015$; 95%CI_{dif} = 0.12; 2.12); -3 days vs. day 0 ($p < 0.001$; 95%CI_{dif} = 0.96; 4.96), and day 0 vs. +1 day ($p < 0.001$; 95%CI_{dif} = 0.97; 4.97).

Heart Rate Variability

For the RMSSD/MRR ratio (Figure 3), no differences were found between time ($F_{2,48, 37.15} = 1.14$; $p = 0.339$; $\eta^2 = 0.071$ [medium]), group ($F_{1, 18} = 4.13$; $p = 0.060$; $\eta^2 = 0.216$ [large]), and no interaction effect was observed ($F_{2,48, 37.15} = 0.391$; $p = 0.722$; $\eta^2 = 0.025$ [small]). A similar result was found for the LF/HF ratio (Table 1), where there were no effects of time ($F_{4, 60} = 0.841$; $p = 0.505$;

Table 1. Low Frequency/High Frequency Ratio Across Time for the Moderate Weight Loss (MWLG) and High Weight Loss (HWLG) Groups. Data are Presented as Mean and Standard Deviation

	-10 days	-7 days	-3 days	Day 0	+1 day
MWLG n = 9	1.07 ± 0.56	0.78 ± 0.59	1.03 ± 1.64	1.02 ± 0.91	1.14 ± 1.25
HWLG n = 11	1.82 ± 1.41	1.03 ± 0.70	1.21 ± 1.10	1.57 ± 1.65	1.44 ± 1.17

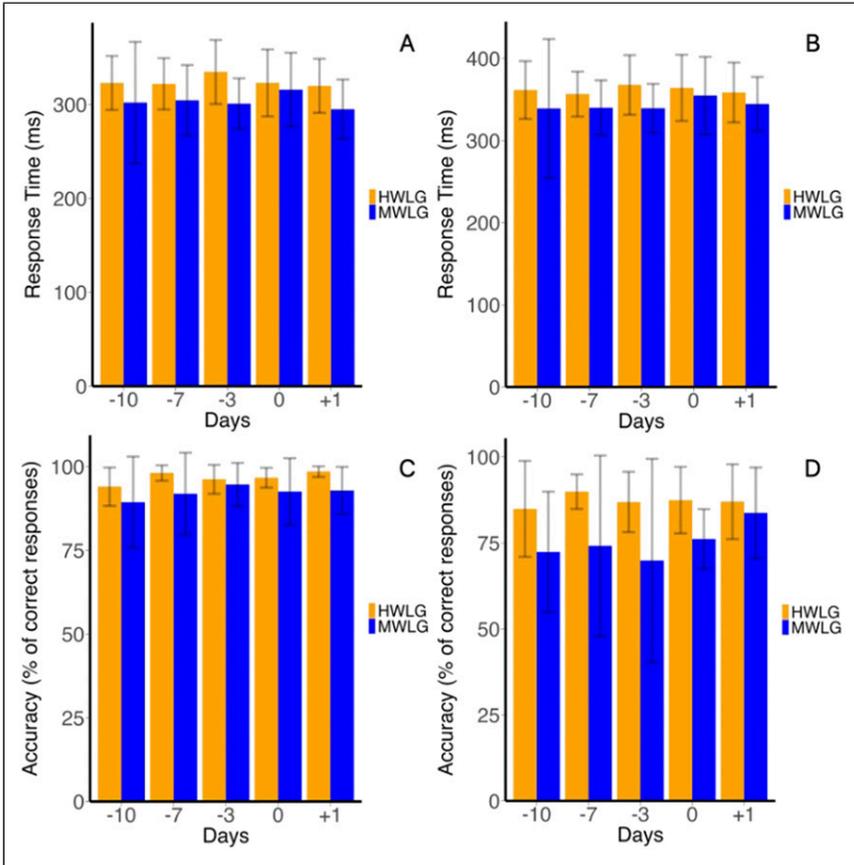


Figure 4. Average Response Time in Congruent Trials (Panel A) and Incongruent Trials (Panel B), Accuracy in the Congruent Trials (Panel C), and Accuracy in the Incongruent Task (Panel D) of the Flanker Task. MWLG = Moderate Weight Loss Group; HWLG = High Weight Loss Group; MWLG = Moderate Weight Loss Group

$\eta^2 = 0.053$ [small]), group ($F_{1, 18} = 0.855$; $p = 0.370$; $\eta^2 = 0.054$ [small]), or interaction ($F_{4, 60} = 0.585$; $p = 0.675$; $\eta^2 = 0.038$ [small]).

Psychological Component

Figure 4 presents the response times during the congruent trials (panel A) and the incongruent trials (panel B). For the congruent trials, no effects of time ($F_{2,29, 27.53} = 0.279$; $p = 0.788$; $\eta^2 = 0.023$ [small]), group ($F_{1, 18} = 2.89$; $p = 0.115$; $\eta^2 = 0.194$ [large]), or interaction ($F_{2,29, 27.53} = 0.433$; $p = 0.680$; $\eta^2 = 0.035$ [small]) were observed. Similar results were found for the incongruent trials, with no effects of time ($F_{2,29, 27.53} = 0.185$; $p = 0.817$; $\eta^2 = 0.015$ [small]), group ($F_{1, 18} = 1.04$; $p = 0.328$;

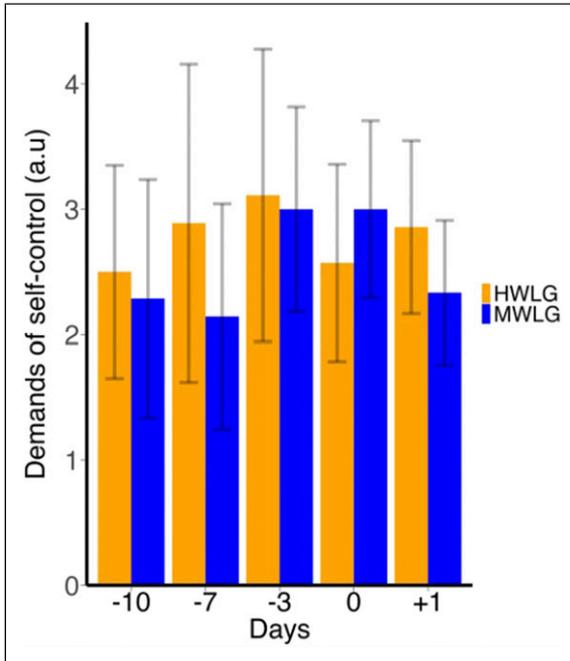


Figure 5. Demands of Self-Control for the HWLG Group and MWLG Group Recorded 10 Days, 7 Days, and 3 days before the Weigh-In, on the Weigh-In Day (0), and on the Competition Day (+1). HWLG = High Weight Loss Group; MWLG = Moderate Weight Loss Group

$\eta^2 = 0.080$ [medium]), or interaction ($F_{2,29, 27.53} = 0.157$; $p = 0.841$; $\eta^2 = 0.013$ [small]).

Regarding the accuracy during the congruent task (Figure 4(C)), there were no significant effects of time ($F_{2,41, 28.88} = 2.963$; $P = 0.138$; $\eta^2 = 0.147$ [large]), group ($F_{1, 18} = 1.10$; $P = 0.315$; $\eta^2 = 0.084$ [medium]), or interaction ($F_{2,41, 28.88} = 0.629$; $P = 0.569$; $\eta^2 = 0.050$ [small]). Similar results were found for accuracy during the incongruent task (Figure 4(D)), with no effects of time ($F_{1,75, 20.97} = 0.952$; $p = 0.391$; $\eta^2 = 0.074$ [medium]), group ($F_{1, 18} = 2.89$; $p = 0.115$; $\eta^2 = 0.194$ [large]), or interaction ($F_{1,75, 20.97} = 1.107$; $p = 0.342$; $\eta^2 = 0.084$ [medium]).

Demands of Self-Control

For the demands of self-control (Figure 5), the analysis revealed no effects of time ($F_{2,38, 19.08} = 3.02$; $p = 0.065$; $\eta^2 = 0.274$ [large]), group ($F_{1, 18} = 2.79$; $p = 0.133$; $\eta^2 = 0.259$ [large]), or interaction of time and group ($F_{2,38, 19.08} = 1.38$; $p = 0.279$; $\eta^2 = 0.147$ [large]).

Table 2. Technical Variation Index, Scoring Index, and Winning Rate for Moderate Weight Loss (MWLG) and High Weight Loss (HWLG) Groups (Data Presented as Median and Interquartile Range)

	MWLG n = 9	HWLG n = 11
Technical variation index (%)	0.40 (0.14; 0.68)	0.36 (0.23; 0.66)
Scoring index (%)	0.14 (0.00; 0.20)	0.00 (0.00; 0.16)
Winning rate (%)	0.50 (0.00; 0.75)	0.00 (0.00; 0.50)

Technical and Tactical Actions

Table 2 presents the variation index, scoring index, and winning rate. No statistically significant differences between groups were found in these variables: technical variation index ($U = 37.5$; $p = 0.859$; effect size $R = 0.05$ [95% CI = -0.48 ; 0.51 ; small; 95% CI diff = -0.44 ; 0.80]); scoring index: $U = 43$; $p = 0.437$; effect size $R = -0.17$ [95% CI = -0.59 ; 0.34 ; small; 95% CI diff = -0.01 ; 0.04]); winning rate: $U = 42.5$; $p = 0.412$; effect size $R = -0.18$ [95% CI = -0.62 ; 0.30 ; small; 95% CI diff = -0.45 ; 0.17]).

For the temporal structure variables (**Table 3**), no differences were found for any of the variables: total standing combat time: $U = 51$; $P = 0.862$; effect size $R = -0.05$ [95% CI = -0.47 ; 0.31 ; small; 95% CI diff = -374 ; 294]; total groundwork combat time: $U = 47.5$; $p = 0.670$; effect size $R = -0.05$ [95% CI = -0.44 ; 0.33 ; small; 95% CI diff = -132 ; 53]; total attack time: $U = 48$; $p = 0.702$; effect size $R = -0.09$ [95% CI = -0.52 ; 0.36 ; small; 95% CI diff = -109 ; 202]; total approach time: $U = 49$; $p = 0.754$; effect size $R = -0.07$ [95% CI = -0.51 ; 0.37 ; small; 95% CI diff = -84 ; 72]; total gripping dispute time: $U = 53$; $p = 0.972$; effect size $R = -0.01$ [95% CI = -0.41 ; 0.38 ; small; 95% CI diff = -302 ; 235]; high/low intensity ratio: $U = 54$; $p = 1$; effect size $R = 0$ [95% CI = -0.44 ; 0.43 ; small; 95% CI diff = -0.77 ; 1.81].

Body Mass Reduction and Cognitive Performance

Correlation analysis revealed statistically significant relationships between body mass reduction and performance on the congruent and incongruent tasks (**Figure 6**). Positive

Table 3. Temporal Structure Variables for Moderate Weight Loss (MWLG) and High Weight Loss (HWLG) Groups (Data Presented as Median and Interquartile Range)

	MWLG n = 9	HWLG n = 11
Total standing combat time (s)	367 (125; 549)	198 (117; 493)
Total groundwork combat time (s)	105 (68; 169)	75 (43; 166)
Total attack time (s)	32 (18; 88)	23 (12; 61)
Total approach time (s)	85 (52; 133)	48 (37; 150)
Total gripping dispute time (s)	293 (93; 417)	143 (81; 311)
High/low intensity ratio	1.33 (1.20; 1.49)	1.08 (0.88; 1.60)

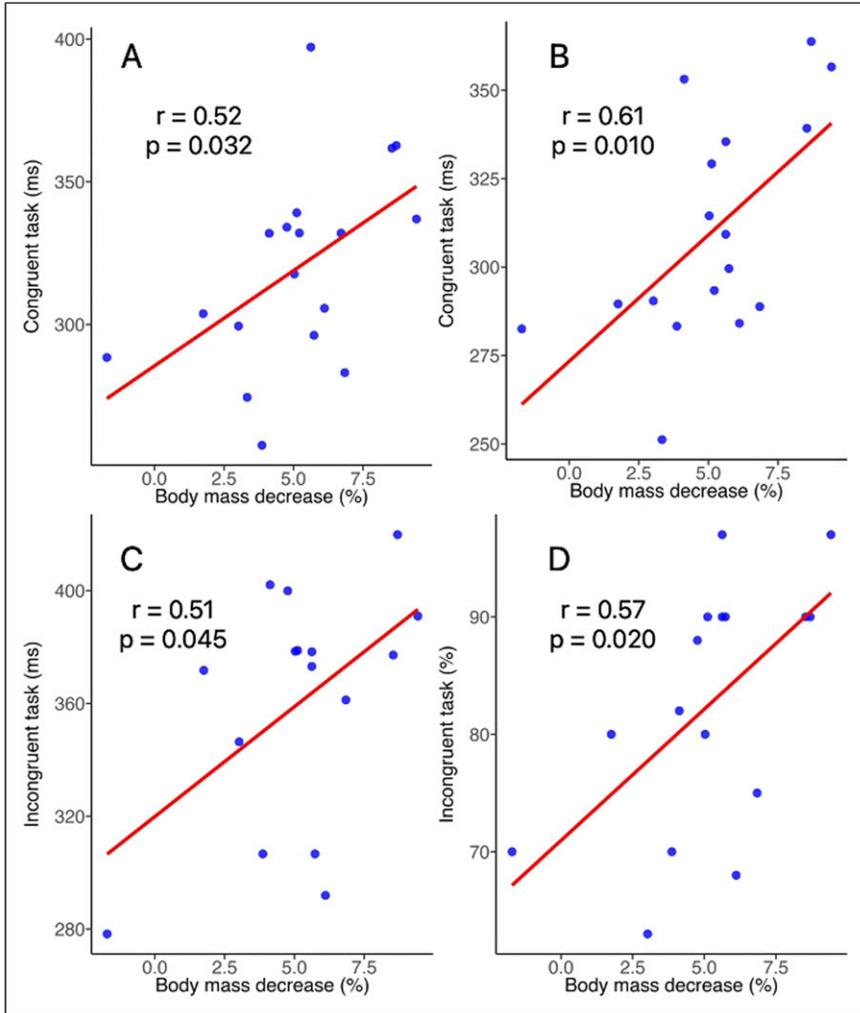


Figure 6. Correlation Between Body Mass Reduction and Response Time on the Congruent Task on Day 3 before Weigh-In (A) and Competition Day (B), Response Time on the Incongruent Task on Weigh-In Day (C), and Accuracy on the Incongruent Task on Weigh-In Day (D)

and moderate correlations were found between body mass reduction and response time on the congruent task on -3 day ($r = 0.52$; 95% CI = 0.10, 0.78; $p = 0.032$; Figure 6(A)) and on competition day (+1) ($r = 0.61$; 95%CI = 0.22, 0.82; $p = 0.010$; Figure 6(B)). No correlation was found for the congruent task on -10 days ($r = 0.27$; 95% CI = $-0.19, 0.63$; $p = 0.283$), on -7 days ($r = 0.33$; 95% CI = $-0.16, 0.69$; $p =$

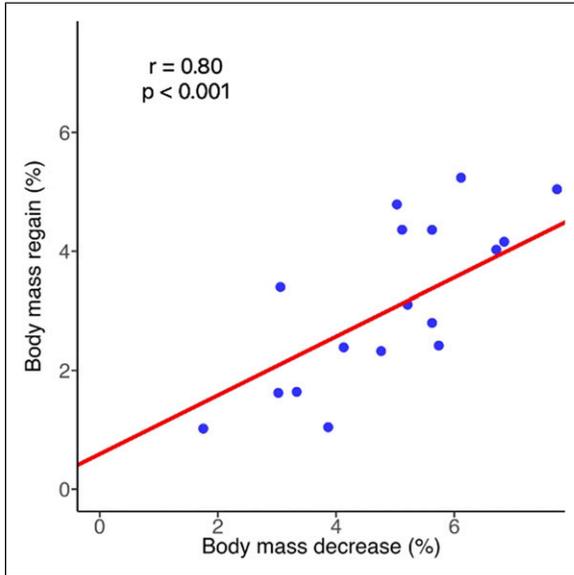


Figure 7. Correlation Between Body Mass Reduction and Body Mass Regain after Weigh-In

0.169), or on the weigh-in day ($r = 0.44$; 95% CI = $-0.09, 0.77$; $p = 0.096$). For accuracy on the congruent task, no significant correlation was found at any point.

Additionally, a positive correlation was observed between body mass reduction and response time on the incongruent task at weigh-in day ($r = 0.51$; 95%CI = $0.08, 0.77$; $p = 0.045$; [Figure 6\(C\)](#)), as well as between body mass reduction and accuracy on the incongruent task at weigh-in day ($r = 0.57$; 95%CI = $0.17, 0.80$; $p = 0.020$; [Figure 6\(D\)](#)). At other points, no significant correlation was found for the incongruent task (-10 days: $r = 0.13$; 95% CI = $-0.35, 0.56$; $p = 0.593$; -7 days: $r = 0.39$; 95% CI = $-0.09, 0.72$; $p = 0.100$; -3 days: $r = 0.37$; 95% CI = $-0.13, 0.72$; $p = 0.138$; or competition day: $r = 0.36$; 95% CI = $-0.16, 0.72$; $p = 0.161$) or for accuracy on the incongruent task (-10 days: $r = 0.11$; 95% CI = $-0.37, 0.54$; $p = 0.655$; -7 days: $r = 0.18$; 95% CI = $-0.31, 0.59$; $p = 0.470$; -3 days: $r = -0.02$; 95% CI = $-0.49, 0.46$; $p = 0.938$; or competition day: $r = 0.10$; 95% CI = $-0.41, 0.56$; $p = 0.688$).

Body Mass Reduction and Body Mass Regain

[Figure 7](#) presents the correlation between the magnitude of body mass reduction and subsequent body mass regain. A strong positive correlation was found ($r = 0.805$; 95% CI = $0.58, 0.92$; $p < 0.001$).

Discussion

The primary finding of this study was that WL was associated with impaired information processing and a cognitive strategy change that seeks to reduce errors in the face of conflicting stimuli. HRV remained stable, suggesting physiological resilience among elite athletes. Importantly, no significant differences in technical-tactical indices or perceived demand of self-control were observed between moderate and high WL groups. It is important to note that these findings highlight associations rather than causal relationships, emphasizing the need for cautious interpretation. These findings suggest that the hypothesis posited at the outset—athletes undergoing WL exceeding 5% of their body mass would exhibit impairments in performance across cognitive, physiological, and technical-tactical performance compared to those with a reduction of 5% or less—was not confirmed.

The observed correlation between body mass reduction and body mass regain reveals a significant relationship: athletes who experienced greater body mass regained a larger proportion of body mass following the weigh-in. This finding underscores the interconnected nature of these processes, particularly in sports like judo, where precise weight management is critical. Previous studies, such as [Reale et al. \(2016\)](#), often inferred the magnitude of body mass reduction indirectly through the extent of post weigh-in body mass regain. However, this approach assumes a direct equivalence between the two variables, which may oversimplify the nuanced physiological and recovery processes involved ([Matthews et al., 2019](#)). Despite the prevalence of WL in combat sports, there is limited research that directly measured and compared both parameters simultaneously ([Bialowas et al., 2023](#); [Ceylan et al., 2022](#)). By addressing this gap, the current study provides novel insights into how body mass reduction and recovery dynamics interact, highlighting the need for accurate assessments to inform evidence-based weight management practices.

Recent findings provide additional context to our observations. [Ceylan et al. \(2022\)](#) demonstrated that WL induced significant dehydration and impaired heart rate recovery, even after 15 hours of recovery, while performance during judo-specific tasks was unaffected. Similarly, [Bialowas et al. \(2023\)](#) found no association between dehydration and competitive performance, emphasizing physiological resilience in elite judo athletes. These studies, together with the present findings, underscore the complex interplay between weight reduction, recovery strategies, and performance outcomes, suggesting that WL effects may vary across physiological, cognitive, and technical-tactical performance.

Despite the physiological demands of WL, no significant differences were found in HRV indices, such as RMSSD/MRR and LF/HF ratios, across groups or over time. This suggests that autonomic nervous system regulation remained stable, potentially reflecting the athletes' ability to adapt to WL routines. While the current findings indicated that WL did not affect autonomic balance, they contrast with previous studies on other combat sports. For example, [Roklicer et al. \(2022\)](#) reported that WL combined with sport-specific training impaired heart rate recovery in Greco-Roman wrestlers, likely reflecting compromised parasympathetic reactivation due to heightened

physiological stress. However, the difference in findings may be attributed to the inclusion of sport-specific training under WL conditions in Roklicer's study, which added an additional layer of stress does not present in this protocol. HRV is a well-established marker of physiological stress and recovery, commonly used to assess athletes' readiness and responses to training (Shaffer & Ginsberg, 2017). The absence of significant effects on HRV in this study aligns with evidence suggesting that aerobic capacity and adaptive mechanisms in well-trained athletes can buffer the physiological stress associated with WL (Stanley et al., 2013).

The findings on cognitive performance in responses to WL reveal highlight aspects for the athletic performance. This study found moderate positive correlations between body mass reduction and cognitive performance variables, particularly increased response times on congruent trials and strategic change towards minimizing errors at the cost of speed on incongruent trials of the Flanker task. Based on the correlations observed between body mass reduction and cognitive task performance, it can be inferred that athletes' weight loss comes at the cost of information processing, while inhibitory control is maintained by adjusting the strategy. This phenomenon could be related to an adaptive mechanism described by Chittka et al. (2009), where more deliberate decision-making compensates for reduced cognitive processing speed, especially under stress. Fortes et al. (2017) reported that WL negatively affected decision-making, which could have implications for combat performance. Thus, the cognitive changes identified in this study may influence the combat dynamics, such as attack timing and adaptation to opponents' strategies. Future studies should explore how these effects on cognitive performance interact with specific tactical and technical variables during critical competition phases, such as elimination rounds.

There were findings showed no significant differences between groups regarding technical-tactical performance variables, including the technical variation index, scoring index, winning rate, and temporal indices, between groups. However, in the present study, all technical-tactical data were collected exclusively from competition day, which highlights the robustness of performance indicators regardless of WL magnitude. Future research should further investigate whether these patterns remain consistent across different contexts or phases of preparation.

Despite the strengths of this field-based design, some limitations must be acknowledged. Firstly, the relatively small sample size ($N = 20$), while common in studies involving elite athletes, may limit the statistical power to detect smaller effects and increases the susceptibility of the findings to individual variability. Furthermore, the sample consisted exclusively of highly trained, elite judo athletes, which affects the generalizability (external validity) of the results to other populations, such as amateur athletes or those from different combat sports. Another limitation pertains to the body mass baseline. Although the measurement was taken 10 days before competition—a common timeframe in the literature (dos Santos et al., 2023)—some athletes might have initiated weight management strategies earlier. This means our baseline might not represent their true habitual body mass, potentially influencing the calculated magnitude of weight loss. However, it is well documented that the greatest decreases occur close to competition, especially in the last week before tournaments (dos Santos et al.,

2023). Finally, the absence of baseline technical-tactical data means we cannot definitively rule out pre-existing differences between the groups as an alternative explanation for the lack of observed effects on performance during the tournament.

Practical Implications

Coaches and physical trainers should consider that WL may affect athletes' cognitive strategies, especially in situations requiring fast and precise decision-making. Therefore, assessing cognitive status after the weight loss process can provide valuable information for adjusting tactical strategies during competition. Optimized recovery protocols should be implemented after weigh-ins to minimize the potential adverse effects of dehydration and cognitive stress. The absence of significant differences in various factors in this study suggests that the athletes may have already adopted effective recovery strategies, such as gradual hydration and strategic carbohydrate intake (Artoli, Iglesias, et al., 2010). Regarding tactical adaptation, coaches should consider that athletes may adopt a more cautious and accuracy-focused approach during matches after WL. This strategic adaptation can be leveraged to reduce the risk of penalties (shido) and maximize scoring opportunities depending on the opponent's style.

Conclusion

This study demonstrated that WL in judo athletes is associated with subtle yet relevant changes in cognitive strategies. Although no direct impact on technical-tactical performance was observed, regardless of whether athletes lost more or less than 5% of body mass, athletes who experienced higher weight reductions displayed slower response times in incongruent cognitive tasks but with higher accuracy. This finding suggests that under pressure, athletes may prioritize minimizing errors over processing speed, reflecting a strategic adaptation to the physiological state induced by WL. While HRV metrics remained stable, suggesting resilience among elite athletes, there was a notable relationship between WL and certain aspects of cognitive performance. These findings emphasize the importance of considering various factors, such as the relationships between body mass changes and recovery, and its potential implications for cognitive performance. Integrated approaches that include weight management, recovery strategies, and cognitive training may help optimize performance under WL conditions.

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Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by CNPq grants 403032/2023-7 and 305507/2023-0, and FAPESP grants 2024/18847-4 and 2024/08930-1.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author Biographies

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