REVIEW ARTICLE

Effect of rapid weight loss in combat sports: systematic review

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 26 January 2023; **Accepted:** 09 March 2023; **Published online:** 23 March 2023

AoBID: 15626

Abstract

Background & Study Aim: Rapid weight loss (RWL) is a process usually practiced by combat athletes. The objective of this review was to know the effects of RWL on cardiac response, executive functions, and mood state, as well as the study methodologies used.

Material & Methods: The search was conducted in Web of Science, Scopus, PubMed, and Google Scholar, in English and Spanish from 2015 to 2022 using the keywords: "rapid weight loss", "acute weight loss", "RWL", "heart rate variability", "HRV", "sympathetic response", "sympathetic cardiac modulation", "executive functions", "cognition", "cognitive", "mood states", and "combat sports". Articles where athletes practiced RWL were included, and the amount of weight lost and at least one variable of interest were reported, considering criteria 1, 10 and 11 of the Spanish's version of the PEDro scale and the PRISMA guidelines.

Results: Seven articles reported an increased heart rate; in terms of executive performance, no significant effects on inhibitory control and reaction time were reported in two articles. Finally, seven articles reported, an increase in tension, depression, anger and fatigue, and a decrease in vigour.

Conclusions: No papers evaluating simultaneously all three variables of interest were found. The effects of RWL appear to be unclear in the analysed articles used, considering the diversity in the methodologies used, it is recommended to carry out studies involving biopsychosocial factors, such as the level of sports and competitive experience of the participants; as well as having standard indicators and methodologies to know the real effect of RWL.

Keywords: cardiac response • emotion • executive functions • weight cycling

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: Not required

Provenance & peer review: Not commissioned; externally peer-reviewed

Source of support: Scientific and Technological Research Support Program

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INTRODUCTION

Combat sports are known to categorize their athletes by their body mass (BM) within weight divisions to minimize size differences between rivals to match the level of competition and reduce the risk of injury among opponents [1]. However, most combat athletes usually use a process known as "weight cutting" or "making-weight" achieved in a week prior to competition through rapid weight loss (RWL) with strategies such as partial or total food deprivation and dehydration [2-7]. The effects of RWL reported in the scientific evidence are diverse and depend on the type of sport evaluated, the type and quantity of strategies used, the number of days of reduction and lost weight [8] but also the methodologies used in the studies for its evaluation.

It is known that the prevalence of RWL is high in these sports, so it is important to know its global consequences. The impact of RWL (in the short and long term) on emotions has been mostly reported [10, 9, 7], and less is known about executive functions [11, 4], and [12, 13].

There are different strategies to quickly achieve the desired weight, such as calorie intake deprivation in a specific time window on a day where the post-consumption period usually lasts a long time after the last intake [14], and the loss of fluids and sodium by the body through increased exercise, reduction or deprivation of fluid intake, use of saunas, among others known as dehydration [15-17].

It has been reported that extreme dehydration causes an increase in heart rate (HR) and a decrease in the difference in arteriovenous oxygenation during sub-maximum exercise [18], as well as the increase in training volume [19], which has a negative impact on sports performance and health [1], an increase in central temperature, cardiovascular stress with a glycogen deficiency and alterations in metabolic function [20, 21]. However, a single study has analysed sympathetic-parasympathetic cardiovascular modulation through HR and heart rate variability (HRV) at the time of rapid weight reduction [12] reporting an increase in HR as well as an increase in the modulation of low frequency band of pulse interval (LF-PI %). Other authors have also reported an increase in resting HR when using RWL [22-26].

Regarding executive functioning, on the one hand, alterations in executive functions have been reported, specifically inhibitory control when athletes lose weight quickly [27-29] where there is a contradiction in the reported results, some authors have studied reaction time for tasks that demand attention or visual abilities, and they found a negative effect [30, 27], while others did not find any effect [31].

Finally, emotions, which have been considered a precompetitive indicator of performance [32] have been the most studied variables when practicing RWL [30, 10, 28, 9, 12, 24, 33-42] an increase in tension, depression, anger, and fatigue as well as a decrease in vigour, but also a sense of self-confidence for having achieved the target weight, have been reported [43].

Although there are systematic reviews of the effects of RWL, the studies involved assess the impact away from the competitors' reality. For example, some sports do not have the opportunity to recover from this practice as they compete on the day of weighing. In addition, most do not have a structure to perform the procedure or are advised by nutritionists or doctors to perform the RWL and its recovery [44].

In addition, there are new studies about HRV and not just HR, which provide new information and new lines of research to perform their evaluation in conjunction with emotions. On the other hand, the variables chosen in the studies to determine executive functioning have been varied, so it is necessary to determine which are most used executive functions in combat sport and after choosing the appropriate instrument for its evaluation.

The above mentioned, does not allow us to obtain a conclusion about the effects of RWL on athletes' health. Considering the worldwide popularity of combat sports, the number of athletes practicing RWL despite the risk of damaging their health, professionals in sports psychology and medicine are concerned about it [45].

Therefore, the objectives of this review was to know the effects of RWL on cardiac response, executive functions, and mood state, as well as the study methodologies used.

Combat sport – *noun* a sport in which one person fights another, e.g. wrestling, boxing and the martial arts [89].

Brazilian Jiu Jitsu – is a type of fight in which a uniform or gi is used; its main purpose is to project or take your opponent down. Once on the ground, you must seek to control your adversary with different techniques (immobilizations, chokes, joints locks). In the absence of submission at the end of the fight, the winner is declared by the number of points won [90].

Muay thai – or *thai boxing*, originates from southern Asia (not only from Thailand, but also from Burma, Cambodia, Vietnam and Malaysia). It was inspired by fighting skills used on battle fields during wars conducted by the Thais in the twelfth and thirteenth century AD. Apart from a fight with use of various weapons, during hand-to-hand fighting warriors used ***kaad chuek*** (wrappings around hand and fore-arm) which were hardened and studded with gravel to cause the greatest damage possible martial art originally from Thailand characterized by the combined use of fists, elbows, knees, shins and feet [89].

Neo-gladiator – a person who trains mix martial arts (MMA) and similar forms of hand-to-hand fighting that do not meet the definition of sport according to the Olympic Charter [91] (see also [92]).

CZĘSTOCHOWA DECLARATION 2015: HMA against MMA – "continuous improvement of health through martial arts as one of the most attractive form of physical activity for a human, accessible during entire life should constantly exist in public space, especially in electronic media, to balance permanent degradation of mental and social health by enhancing the promotion of mixed martial arts – contemporary, bloody gladiatorship, significant tool of education to aggression in a macro scale".

Gdansk 2nd HMA World Congress Resolution – **Article 1** The white flag with five interlocking "Olympic rings" is the most recognizable symbol in the global public space. Neither did the resurrected idea

MATERIAL AND METHODS

Search strategy

Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology [46], the articles search for this systematic review was conducted in Web of Science, Scopus, PubMed, and Google Scholar, in the languages of Spanish and English from 2015 to 2022 with a combination of keywords listed in columns A and E or F and J; and any combination of columns B, C, and D or G, H, and I, in their respective languages (Table 1).

Selection strategy

After the computerized search, the articles were selected by title, structured abstract, objectives, methods with their protocols, as well as inclusion/exclusion criteria. Parallel clinical trials with control group or cross-design were selected as well. Repeated articles, in another language or involved another sport were rejected. As exclusion criteria theoretical or systematic reviews, meta-analyses, book chapters, theses and communications to conferences were discarded.

Eligibility criteria

To minimize possible biases in the article selection the following selection criteria were applied: those articles exclusively involving combat sports participants regardless of the level of competition (amateur, collegiate or professional); to evaluate the effects of RWL including detailed timing of the tests; to report the type of strategies used, the amount of weight loss or percentage, and the time of use prior to the final evaluation; and to compare the effects of RWL between at least two groups, those who practice and those who do not; the comparison between those who lose more or less percentage of weight or the comparison before and after the RWL. Articles reporting at least one outcome measure of the variables of interest (cardiovascular response, executive functions and/or emotions) were also included as long as they reported the measuring instruments.

For the final selection of the articles, criteria 1, 10 and 11 of the PEDro scale were used in its Spanish version [47] considering the data collection process, possible biases, exploration of article inconsistencies, analysis results reported by articles, discussion, limitations, and conclusions. Same criteria above mentioned of the PEDro scale was used to evaluate the external validity and statistical interpretability. Most of the included articles met all three criteria. The article by Camarço et al. [29], Nascimento-Carvalho et al. [12] and Slačanac et al. [48] met two criteria, while the work of Kim et al. [49] only met one criterion of statistical interpretability.

Table 1. Keywords used for the search.

English					Spanish				
A	B	C	D	E	F	G	H	I	J
Rapid weight loss	**Heart rate variability**	**Executive functions**	**Mood states**	**Combat sports**	**Pérdida rápida de peso**	**Variabilidad de la frecuencia cardíaca**	**Funciones ejecutivas**	**Estado de ánimo**	**Deportes de combate**
or	or	or			or	or	or		
RWL	HRV	cognition			pérdida aguda de peso	VFC	cognición		
or	or	or				or			
acute weight loss	sympathetic response	cognitive				respuesta simpática	cognitivo		
	or					or			
weight cycling	cardiac sympathetic modulation					modulación cardio simpática			

Note: **HRV** heart rate variability; **RWL** rapid weight loss; **VFC** variabilidad de la frecuencia cardíaca (heart rate variability)

of Olympia, "Citius, Altius, Fortius" save humanity from the horrors of two world wars, nor did the declared mission of the International Olympic Committee (IOC): "1. (...) the promotion of ethics and (...) ensuring that, in sport, the spirit of fair play prevails and violence is banned" (Olympic Charter, p. 18) stop the pathology of permanently educating contemporary man in aggression. **Article 2** Likewise, symbols (a sword pointed downwards surrounded by five rings) and motto ("Friendship through Sport") of Conseil International du Sport Militaire (CISM) did not stop soldiers from killing each other and murdering people after 1948 (the year of establishing CISM, the second largest multi-sport discipline organization after the IOC, and also the year of the Universal Declaration of Human Rights). **Article 3** Although there are five identical combat sports in the Olympic Games and the Military World Games, their potential is still not used to meet the second of the Fundamental Principles of Olympism: "(...) to place sport at the service of the harmonious development of humankind, with a view to promoting a peaceful society concerned with the preservation of human dignity" (Olympic Charter, p. 13). **Article 4** Boxing and wrestling cultivate the traditions of ancient Olympism. Judo and taekwondo have given martial arts humanistic and health attractiveness. Fencing combines this tradition with modernity in the spirit of chivalry. Aiming dynamic offensive and defensive actions directly at the opponent's body (irrespective of the protectors used) in such a way as not to hurt is a measure of respecting those knightly rules. This rule harmonizes with the principle of respect for the opponent's as well as one's own corporeality and dignity over the vain victory at all costs. **Article 5** For the civilized individual and the society for whom human health and dignity are the common good, participation, in any role, in brutal shows of people massacring each other cannot be a standard of the quality of life. Neo gladiatorship camouflaged under the banner of martial arts or combat sports is a slight to the Fundamental Principles of Olympism, but also to the Universal Declaration of Human Rights. Therefore, this

Resolution should inspire as many actors of Knowledge Society as possible jointly to oppose any deformations of the mission of Olympism and sport. The expansion of the pathology of unauthorized naming neo gladiators as combat sports athletes will soon turn the Fundamental Principles of Olympism into their own caricature – objective indicators are a testament to the devastation of all dimensions of health by the practice of legal bloody pageants [93].

Dan (dan'i) – a term used to denote one's technical level or grade [94].

Making weight – be within the minimum and maximum weight limits designated for the group of competitors at a particular sporting event, especially in combat sports.

Low frequency band of pulse interval – low frequency band heart period rhythms.

Cardiac response – the measure in which we can observe changes at the cardiovascular level, that is in the heart rate or the variability of the heart rate.

Executive functions – cognitive processes that allow control, regulate and plan behaviour, taking as a measure inhibitory control and reaction times in tasks that demand decision-making, since they have been among the most studied variables in the sports field.

Mood state – situation in which the athlete is perceived through his emotions and/or positive or negative affections.

Flight or fight – Automatic mechanism that prepares the organism to act (see also [95]).

Data extraction

The following information was extracted: name of the first author and year of publication; study design; sex, age, sport and sports level of the participants, as well as the number of participants; duration of the RWL in days/hours; type and number of strategies used which were grouped by dehydration or deprivation of calorie intake; average and standard deviation (SD) of lost kilograms, as well as percentage of loss of BM, (it was calculated in those articles that did not mention it). In addition, the measurement of the variables of interest and the measuring instruments were extracted, at the previous and after the RWL, indicating whether the change was significant or not.

RESULTS

Below is the flowchart of the article selection process (Figure 1) that after identification, compliance with inclusion and exclusion criteria as well as with the items mentioned for the quality of studies through the *PEDro* scale, 13 articles were included in this review (marked with an asterisk [*] in the list of references) which are presented in Table 2 with the different variables of interest that were grouped in three columns as: cardiac response (comprising heart rate and/or its variability); executive functions (including inhibitory control and time index of decision making) and, finally, moods (including positive and negative affects).

The data in Table 2 illustrates the main features of the articles in our systematic review above mentioned. We obtained seven articles that study cardiac response, two about executive functions and seven regarding mood state. The studies evaluated an average of 23.23 participants in the current systematic review with a duration of weight reduction through RWL strategies of 10.88 days, the number of strategies used were 2.92 ±1.73 by dehydration and 1.31 ±0.63 by deprivation of calorie intake, and an average of 6.37 ±3.97 percentage of loss of their BM.

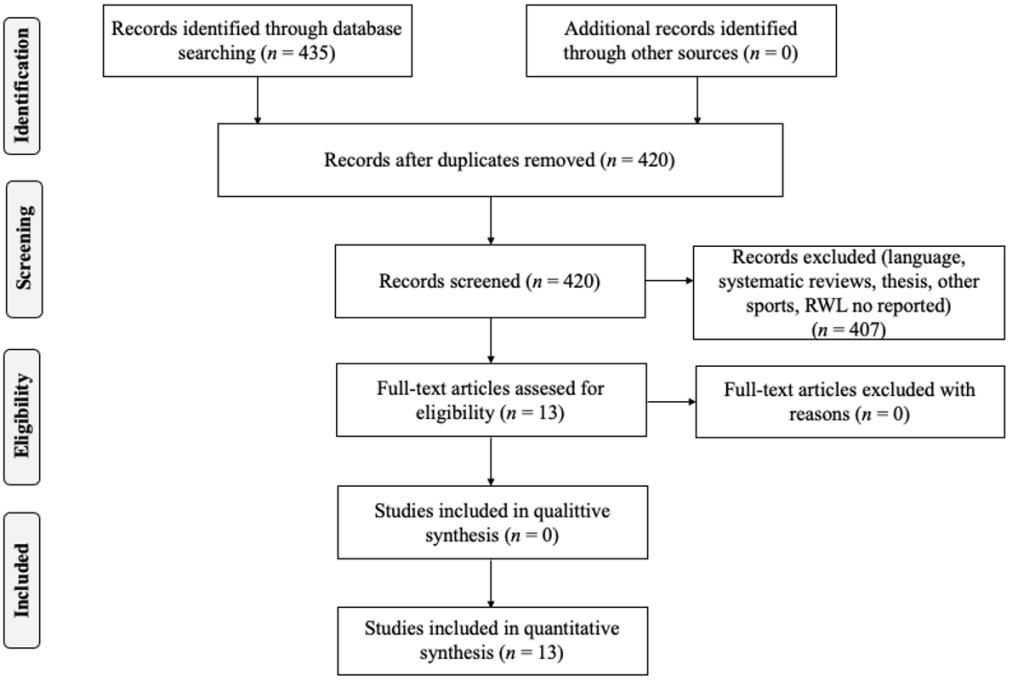

Figure 1. Flow chart of the different steps for the selection of the included articles in this systematic review.

Table 2. Final articles included in the systematic review according to the criteria research.

Authors, year of publication	Sample, size, sex, age, combat sports, level	Design and procedure days using RWL strategies	(Number) Common methods used RWL by dehydration	Common methods used RWL by caloric intake (Number)	Amount (kg) and (%) of weight loss	Cardiac response	Executive functions	Mood state
Abedelmalek et al. 2015 [8]	Non probabilistic 11 males 20.45 ±2.51 years judo National level with second and third dan	Simulated: (I) Baseline (normal condition diet). (II) Evaluation with the test SJFT after 7 days of CR.		(I) Calories restriction by 6.7 MJ/day.	75.9 ±3.1 kg to 72.73 ±3.1 kg** 4.18% approx. of their BM.	Automatic Blood Pressure ↑HR immediately: 182.3 ±5.3 to 188 ±8.4 bmp** ↑HR after 1 min: 154 ±2.8 to 161 ±3.2 bmp**		
Carmarço et al. 2016 [29]	2 males Athlete 1 Athlete 2 22 years MMA 3 years of professional experience	Simulated: (I) 7 days before combat. (II) 36 h before combat. (III) in the combat day simulated.	Athlete 1: (2) Ingested six L of water during the first 5 days of RWL and, before weigh-in, performed restriction of water and sodium. Athlete 2: (1) Ingested 2 L of water during the first 6 days of RWL and water restriction, and not restrict of sodium.	Athlete 1: (2) Caloric ingestion of 708 ±428 kcal and 3 days of fasting. Athlete 2: (1) Maintained a balanced diet of 1600 ±0 kcal and one day of fasting.	Athlete 1: 7.2 kg or 9.1% of BM. Athlete 2: 4 kg or 5.3% of BM.		Stroop Color-Word Test computerized No significant changes. Athlete 1 had more errors in the three tasks than Athlete 2. And compared to the same subject at the measure (III).	
Fortes et al. 2017 [22]	Non probabilistic 39 males 18 to 25 years judo Nationallevel	Simulated: (I) Two weeks prior to performed the test. (II) After to perform the RWL. Structured weekly loss of approx. 5%.	(3) Use of rubber suits during training, sauna, and laxatives.	(1) Fasting.	EG: 72.5 ±3.6 change to 64.8 ±4**; CG: 73.1 ±3.9 to 72.6 ±4.2** 10% of their BM.	Polar RS800CX EG: ↑HR 1 min after SJFT: 135.8 ±5.0 to 144.3 ±4.2 bpm†		
Fortes et al. 2017 [50]							Game Performance Assessment Instrument EG: ↑DMI: 0.48 ±0.1 to 0.49 ±0.1 CG: ↑DMI: 0.47 ±0.1 to 0.52 ±0.1†	
Fortes et al. 2018 [41]								POMS EG: ↑tension: 10.8 ± 0.8 to 12.9 ±0.9**, ↑Depression: 10.2 ±0.9 to 12.6 ±1.1**, ↑anger: 9.9 ±0.7 to 13.4 ±0.8**, ↑fatigue: 8.6 ± 0.8 to 15.6 ±0.7**, ↑confusion: 9.4 ± 1.1 to 9.7 ±0.9, ↓vigour: 19.3 ± 0.9 to 14.3 ±1.0**. CG: ↑vigour: 19.8 ±0.7 to 22.2 ±0.8**

Authors, year of publication	Sample, size, sex, age, combat sports, level	Design and procedure days using RWL strategies	(Number) Common methods used RWL by dehydration	Common methods used RWL by caloric intake (Number)	Amount (kg) and (%) of weight loss	Cardiac response	Executive functions	Mood state
Nascimiento-Carvalho et al. 2018 [12]	Non-probabilistic 8 males 21.62 ±1.49 years MMA, Brazilian Jiu-jitsu, Muay Thai 13.37 ±5.78 years of competitive experience	Real competition: (I) 14 days before competition. (II) 1 day before the official weight-in.	(4) Liquid restriction, use of diuretics, and increase of training.	(1) Restriction of carbohydrate and lipids.	71.25 ±3.54 to 69.33 ±4.08 kg. 2.7 % of BM.	Polar RS800 and software Kubios ↑HR: 54.91 ±2.54 bpm to 65.43 ± 3.40 bpm** ↑LF-PI (%): 2942 ±655.3 to 5479 ±2035**		BRUMS ↑Anger: 5.50 ±1.42 to 11.33 ±1.89**, ↑Fatigue: 5.37 ±1.51 to 11.83 ± 2.05**, ↓Vigour: 11.25 ±1.27 to 7.16 ±1.77 **
Brandt et al. 2018 [40]	9 males 25.6 ±4.5 years MMA National level	Real competition: (I) 30 days before competition. (II) at the official weigh-in (one day before competition). (III) 10 minutes before competition. (IV) 10 minutes post competition.	(4) Manipulation of water and sodium levels, use warmer clothes during training and saunas.	(1) Lower carbohydrates intake (50 g·d^{-1}).	EG: 11.6 ± 3.5 kg. Change from 73.6 ±1.8 kg to 66.2 ±2.4 kg‡ 10.1 % of their BM.			BRUMS EG: ↑Confusion before the competition**
Kim et al. 2018 [49]	Non probabilistic 7 males and 18 females, age no reported judo National level	(I) Rapid Weight Loss Questionnaire was applied prior to a match. 4.44 ±2.86 days using RWL.	(7) Limit water intake, wear sweat suit for training and sauna, increase the amount of exercise, work out in the training room, and laxatives.	(3) Gradually reduction of meal portion, skip meals, and fasting.	Reduction of 3.71 ±1.8 kg for male and 2.58 ± 1.28 kg for female. 3.28 ±1.43 % of their BM.			RWL Questionnaire ↑frustration, ↓concentration, ↑depression, and ↑anxiety.
Isacco et al. 2019 [24]	Non probabilistic 20 males 24 ± 5 years Judo National level (Black belt)	Simulated: (I) to (V): Five combats separated by 30 minutes of rest. One week using strategies of RWL.	(1) Decreased the volume of fluid consumption.**	(I) Decreased carbohydrate, fat, and protein intake.†	EG: 3% of their BM† CG: 1.2% of their BM.	Polar PE4000 Electro EG vs CG ↑CCR: 85 ±3 to 83 ±7.		POMS EG vs CG in the final combat. ↑depression: 38 ±4 vs 36 ±2**, ↑anger : 44 ±4 vs 43 ±4**, ↑fatigue : 53 ±9 vs 50 ±5 ‡, ↓vigour: 49 ±12 vs 53 ± 9**, ↓confusion: 40 ±7 vs 37 ±3.‡
André et al. 2021 [25]	21 males of which 16 performed the RWL 22.3 ±1.5 years judo black belt, degree: 1st dan to 3rd dan	Simulated: (I) to (XI): S_1 to S_{11}. HR at rest (HR_0) and HR measurement was taken at the end of the technical-tactical period. 5.5 days using RWL.	(4) Restriction of water intake (some intake only 0.5 L during the rpogram); the increase in energy expenditure combined with the practice of long jogging, diuretics, and laxative.	(2) Restriction of food intake, and drastic restriction of specific intakes.	G_1: 3.1 kg G_2: 4 kg G_3: 5.2 kg 4 – 5.5% of their BM.	Polar Pro Team dock ↑HR_{rest}: 66.8 ±1.8 to 97.4 ±3.5 at the end of the warm-up vs 180.5 ±4.9 bpm at the end fight** Correlation with the lower category and higher the increase in HR.		

Authors, year of publication	Sample, size, sex, age, combat sports, level	Design and procedure days using RWL strategies	(Number) Common methods used RWL by dehydration	Common methods used RWL by caloric intake (Number)	Amount (kg) and (%) of weight loss	Cardiac response	Executive functions	Mood state
Langan--Evans et al. 2021 [51]	1 male 19 years TKD 5 years of experience	Real competition: (I) Loss plan consisting of 7-wk energy intake. (II) before weigh-in. (III) 1 week post competition with energy takes ad libitum. 8 weeks of controlled reduction of Energy Intake (1200–300 cal·d^{-1}).		(1) 5 days of reduced Energy Intake (1200–300 kcal·d^{-1}).	72.5 kg (phase I) to 62.7 kg (Phase II) 13.52% of their BM.	Echocardiography ↓HR consistently across Phases I and II with a large increase in both measures within 24 h from one day to weigh-in, which plateaued by the end of the Phase III.		POMS (Phase I to Phase II) ↑tension: 5 to 8, ↑depression: 3 to 4, ↑anger: 3 to 9, ↓vigour: 22 to 11, ↑fatigue: 3 to 12, ↑total mood of disturbance: – 2 to 28.
Slačanac et al. 2021 [48]	96 males 18.50 ±3.58 years wrestling Greco-Roman 7.78 ±4.06 years of experience	Real competition: (I) Data were collected during the weighing/ before the start of the competition.	(1) Dehydration.		2.25 ±2.22 kg. 3.15 ±3.01 % of their BM**			POMS Correlation*** with increased weight loss and emotions of ↑anger, ↑depression, ↑fatigue, ↑calmness.
Roklicer et al. 2022 [26]	10 males 22.44 ±4.53 years Greco-Roman wrestlers National level	(I) High intensity sport-specific training (HISST) combined with RWL performed in two days before the evaluation. (II) Seven days after only the HISST.	(2) Increased exercise and fluid restriction.	(I) Skipping meals.	Base line 73.36 ±4.42 kg to Phase (I) 69.27 ±4.12 kg ‡ to Phase (II) 72.38 ±4.17kg ‡ 5% of BM.	Polar-H10 HR sensor, Polar Pro chest strap with the application Polar Team ↑ HR values in Phase (I) vs Phase (II) in the first minute of recovery 169.77 ±8.94 vs 158.22 ±12.07 bpm‡ And in the second minute of recovery 151.44 ±11.92 vs 143.88 ±11.78‡ bpm.		

Note: BM body mass; BMP beats per minute; BRUMS Brunel Mood Scale; CG control group; CR caloric restriction; DMI Decision-Making Index; EG experimental group; G_1 judoists category −66 to −60 kg; G_2 judoists category −90 to −81 kg; G_3 judoists category +100 to −100 kg; HR heart rate; LF-PI low frequency band of pulse interval; MJ mega joules; MMA mixed martial arts (see glossary: neo-gladiator); POMS Profile of Mood States; RCC relative cardiac cost; RWL rapid weight loss; SJFT Special Judo Fitness Test; TKD taekwondo; ** $p<0.05$; † $p<0.01$; ‡ $p<0.001$; ↓ decrease in the values; ↑ increase in the values, these articles have the same sample, design and procedure, common methods used for RWL, and amount of weight lost.

DISCUSSION

Due to the high prevalence of RWL it is extremely important to know its effects, so the aim of this study was to know the effects of RWL on cardiac response, executive functions (inhibitory control, working memory, mental flexibility, and reaction time) as well as mood state, emphasizing the methodologies used.

The effects of RWL on sports performance have been extensively studied, and physical and hormonal effects have been reported, producing more susceptibility to cramps, injuries and muscle fatigue, hormonal imbalance, reduced bone density, alterations in metabolic rate and growth, among others [52, 18, 9, 53-55, 45, 39, 43, 56, 7].

Effects on physical performance have also been reported, such as alteration in isometric strength, maximum hand and forearm strength, and anaerobic and aerobic capacity measured in the lower extremities [18, 20, 9, 57, 58, 4, 1, 5, 59, 7, 60, 61]. Other studies have investigated the relationship between RWL and sports success [10, 62,

63, 4, 64, 7, 17] in which there are opposite conclusions, mentioning that acute weight gain after rapid weight reduction seems to be beneficial, while others mention that it is due to sport and competitive experience, however, the physical and mental health of athletes should be a priority when using any strategy or method to improve sports performance.

Effects of RWL on cardiac response

First, in terms of the cardiac response, measured through HR and its variability, we know that the latter represents the dynamic balance between sympathetic and parasympathetic activity that causes continuous oscillations of HR, that is, a variation of time between heart beat-beat (R-R intervals), so it is a non-invasive instrument that, in terms of field application, helps us control the training load and know the physiological state of the athlete avoiding an overtraining syndrome [65-69].

Some authors have studied the relationship between HR and RWL as Fortes et al. [22] who compared two groups, one of them reduced about 5% of their BM with strategies involving dehydration and fasting, while the control group reached their weight with a controlled and supervised diet. The evaluation to measure HR was a specific test for the sport, therefore, not all the factors involved in a real fight were presented, reporting that after one minute of the test, the experimental group did not recover as the control group did. On the other hand, Abedelmalek et al. [8] also carried out a study with an experimental group and control group when the RWL is implemented, through the controlled caloric restriction in a week, an increase in HR was also found. Likewise, the authors André et al. [25] reported an increase in HR in those athletes who lost between 4% to 5.5% of their BM by means of diverse strategies such as food and beverage deprivation, which were also controlled, use of saunas, increased exercise, and diuretics in an average of 5.5 days.

Similar results are reported in the study by Isacco et al. [24] where athletes who lost 3% of their BM in a period of 7 days had an increase in HR, while in the study by Langan-Evans et al. [51] an athlete who reduced 13.5% of his BM, performed over a period of 8 weeks (first evaluation) where a week prior to weighing (second evaluation) there was a drastic calorie reduction for a real competition reported a decrease in HR between the first and second assessment, but despite the fact that HR was no greater than in the first evaluation, there was a considerable increase in HR between official weighing and competition. Roklicer et al. [26] also report an increase in HR one and two minutes after finishing a specific test of the sport in wrestlers who lost 5% of their BM in two days. Finally, Nascimento-Carvalho et al. [12] studied the effect of RWL in HR, where athletes lost less than 5% of their BM finding an increase in HR associated with greater sympathetic modulation was observed after the weight loss strategy on the day of weighing.

The results of these studies show that, regardless of the percentage of the weight lost, all experienced an increase in HR. Contrary to what was reported by some authors [21, 62, 4] who mention that there is no negative effect as long as less than 5% of their BM is reduced. In addition, Cannataro et al. [70] mention that a supervised reduction mitigates the impact of RWL on biological markers, however, hormonal damage is inevitable. Negative effects have also been reported after 12 hours [71], moreover, Maughan et al. [14] mention that 13 hours are not enough to recover. Therefore, the optimal time for recovery of the RWL is unknown which drives the athletes to show up in their combat in non-optimal conditions with likely negative consequences on health and sports results.

On the other hand, athletes who use induced dehydration can achieve weight loss up to 5% of BM or more by combining it with other strategies, causing a physiological effect on the homeostasis by affecting the bar reflex control, increasing sympathetic activity and decreasing parasympathetic activity [72-74, 69]. Therefore, the National Collegiate Athletic Association (NCAA) and other institutions have adopted a measurement of the Specific Gravity of Urine (U_{sg}) of ≤1.020 to identify a state of dehydration for weight certification and physiological purposes, which is the simplest and most practical way to measure hydration status; being an optimal value of hydration status, while higher values indicate a state of mild to severe dehydration [75]. This measurement could be well used by coaches and athletes in their periodic evaluations of training control.

Effects of RWL on Executive Functions

Second, executive functions are defined as a series of capabilities that allow control, regulation and planning of cognitive behaviour and

processes [76]. One of the target process studied in relation to RWL is inhibitory control, which was evaluated by Camarço et al. [29] mentioning that the change was not significant in an evaluation of two athletes who lost between 5.3% to 9.1% of their BM, but the athlete who lost more weight did have more errors, but this could be supported by the speed accuracy compensation theory (SAT) which says that decisions can be made faster by sacrificing accuracy [77], however, an error in competition can change the outcome of this.

Another presumable cognitive process affected by RWL is the reaction time, the authors De Sousa Fortes et al. [41] studied decision-making in judo athletes when they make a weight cut, being these who obtained a better result, which may be due to a response as a defence mechanism of the body, where attention during a thirst situation may result in excessive recruitment of specific brain areas [78], and as mentioned above when using strategies for RWL, especially those that include dehydration, there is increased sympathetic activity [69], possibly resulting in reduced blood flow and oxygenation in the upper brain areas resulting in improved tasks that demand attention and decision-making [79, 8] as a probable mechanism associated with flight or fight, characteristic of a state of acute stress.

Other studies have reported no changes in cognitive status after RWL. For example, Choma et al. [30] who performed RWL and rehydration, reported no changes in mental flexibility and working memory. Landers et al. [27] in a study with athletes who performed food restriction for real competition also reported no changes in working memory, mental flexibility and inhibitory control, however, the evaluations were taken 5-10 days and 8-12 hours before weighing and in such tests the retest effect should be considered; and finally Weber et al. [28] report that there are no changes in reaction times in athletes who used dehydration and food deprivation losing less than 3% of their BM for a simulated competition, which can go hand in hand with the reported that <5% of loss of BM does not affect cognitive processing [21, 62, 4]; likely because the level of dehydration does not affect the speed of the nervous-motor impulse.

As for the replacement, the mechanical 'bouncing' or acute weight gain, The American College of Sports Medicine (ACSM) Guidelines on Exercise and Fluid Replacement [80] and the position of the Academy of Nutrition and Dietetics on Nutrition and Athletic Performance [81] recommend fluid intake at levels that meet the body water content of 1.25-1.50 litres per kg loss of BM, this for a limited period (<12 h) since poor or wrong replenishment could have negative consequences such as gastrointestinal discomforts that could affect performance in any way [82]. Knowing this, it is important to consider sports weighing rules.

Effects on RWL on Mood State

Finally, mood, which has been one of the most studied variables, is defined as the situation in which the athlete is perceived, which can vary its duration and can be both positive and negative [32, 51]. The association between RWL and mood has been reported by authors as Brandt et al. [40], Fortes et al. [41], Kim et al. [49], Isacco et al. [24], Nascimento-Carvalho et al. [12], Lagan-Evans et al. [51] and Slačanac et al. [48] have found very similar results: increased anger, depression, fatigue and decreased vigour and, some studies reported increased tension, confusion, even after competition, anxiety, frustration, and decreased concentration. In the article by Slačanac et al. [48] they reported a sense of calm, probably by having reached the target weight, and by a sense of belonging to perform the RWL [43]. These results are very similar regardless of the study methodologies, percentage of weight lost (ranging from 2.7 to 13.52% of the BM), number of days and type of strategies used, so it seems that RWL affects the emotional state of the athlete. However, we must be careful with such statements, since there are biases that could affect these results, we must be more careful with the variables that can be controlled, and perform these studies in competitive situations, since this can be one of the variables with greater affectation, as well as the stress to which they may be subjected when following weight strategies that are not commonly used as well as being under the supervision of a protocol for weight reduction.

Methodologies

Other factors to consider are the number of days in which they achieve this reduction, whether it was controlled, and the number and type of strategy used, the experience of the athlete, as well as the absence of a real competition. As for the type of strategy, studies using food restriction seem to

have a greater control of quantity (caloric count and supervision of a nutritionist), but the reality is that weight loss processes are empirical, athletes do not have a guide from health professionals and are recommended by people who do not know the consequences of RWL [83].

As mentioned by Camarço et al. [29] it is difficult to compare the results of this variable, because the protocols are very varied, so it must be reconsidered which executive functions allow us to know the cognitive performance in each combat sport. Therefore, it is essential to consider the rules of sport to perform a proper rehydration. Another point to consider is that none of the studies that considered a replacement of water and food was with placebo effect and in most studies was controlled, therefore fluid deprivation can have minimal or no effect on cognitive performance if the measured result is not sensitive to the effects of actual weight loss through dehydration strategies or calorie intake deprivation. In addition, hormone levels should be considered, such as oestrogen, which is related to executive functions, considering gender differences [84].

Finally, the use of HRV to know the psychological state of the athlete can be of great help, since different indicators are associated with psychological constructions such as cognitive abilities, neuronal processes, and personality traits [85]. This would allow future research to broaden the approach of HRV from a psychological perspective and not only physiological. And being a practical and non-invasive tool, trainers, psychologists, and athletes, supported by short psychological questionnaires, could keep a regular physiological and psychological record, since the long-term impact of staying close to your weight is evident, as athletes have reported feeling dissatisfied, anxious and concerned about their body image [86, 87] therefore, it is not only important to take care of emotions prior to a competition but also the psychological repercussions that weight management can have [88].

CONCLUSIONS

The effects of RWL on cardiac response appear to be an increase in HR when performing a RWL, only one article mentions a decrement, but the methodologies used to make a conclusion must be considered. As for executive functions, it is difficult to make a discussion and conclusion because the articles mentioned present different variables to measure cognitive performance. Finally, the mood state seems to be the most consistent variable in the results, although an improvement appears to be influenced by the satisfaction of having achieved the objective weight.

It is proposed to establish methodologies that resemble what athletes do, for example, professional athletes will have the time to make a replenishment of a day, although it is also known that these are the athletes who lose more weight. On the other hand, college athletes and novices competing on the day of weighing will not have the opportunity to apply weight gain or replacement strategies. It is important to evaluate the effects of RWL as near as possible to the competition considering the rules of each discipline, if they have time to recover and if this time is enough, in addition to creating specific protocols for each discipline. Also, sport and competitive experience must be considered. Likewise, it is proposed to take the assessments of athletes from their entry into sport to know the long-term effects and choose the variables with their corresponding measurements by sport, considering the established rules of weighing, as well as physical and psychological factors, to make an overall assessment. Finally, psychoeducation is proposed through interventions to coaches and athletes on the consequences of RWL, considering all biopsychosocial factors that lead athletes to use RWL.

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Cite this article as: Castor-Praga C, Sanchez-Lopez J, Lopez-Walle JM et al. Effect of rapid weight loss in combat sports: systematic review. Arch Budo 2023; 19: 83-94